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IN-SERVICE PERFORMANCE AND COSTS OF METHODS TO CONTROL URBAN RAIL SYSTEM NOISE

INITIAL TEST SERIES REPORT

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INTERIM REPORT

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16. Abstract

The purpose of this project is to determine the acoustic and economic effectiveness of resilient wheels, damped wheels, wheel truing, and rail grinding for reducing wheel/rail noise on urban rail transit systems. The project consists of a six-phase series of field tests being performed on the Southeastern Pennsylvania Transportation Authority System's Market Frankford Line, and in-depth interviews with management and operating personnel of the North American steel wheeled rapid transit systems regarding their experience with the above mentioned noise abatement procedures.
This is the third report of this project. The first two reports, the Experimental Design and the Test and Evaluation Plan contained the procedures to be followed in conducting the project. This report includes: (a) the results of the testing performed in Phases I, II, and III including tentative recommendations; (b) changes which have occurred to the Experimental Design and to the Test Evaluation Plan; (c) economic data for the wheel types, rail grinding equipment, and wheel truing equipment under consideration; (d) a preliminary discussion of problems and enumeration of constraints which are relevant to use of these techniques on other systems; (e) a summary of remaining testing to be accomplished under the program including recommended changes to the Experimental Design or to the Test and Evaluation Plan.

It has been determined that overall noise reduction obtained by use of the various techniques is limited by the noise of the propulsion system.

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PREFACE

This interim report presents the results of the initial test series and the economic data developed as of September, 1977. The purpose of the program is to develop information on the costs and effectiveness of four methods of controlling wheel/rail noise: resilient wheels, damped wheels, wheel truing and rail grinding. The ultimate goal is to provide information on the noise control methods that individual transit systems can use to evaluate the costs and benefits that would result from application of the methods. The study, sponsored by the Office of Rail and Construction Technology of the Urban Mass Transportation Administration, Office of Technology Development and Deployment, is managed by the Transportation Systems Center (under Contract DOT-TSC-1053) as part of the Urban Rail Supporting Technology Program. This report is the third of the study; the first report defined the experimental design and the second report presented the test and evaluation methods and procedures for determining the benefit to be gained from the noise reduction techniques examined.

The report has been prepared jointly by De Leuw, Cather & Company (DCO) and Wilson, Ihrig & Associated, Inc. (WIA). The work was technically directed by Robert Lotz and Leonard Kurzweil of the Transportation Systems Center. The work was performed principally by Robert L. Shipley (DCO) and Hugh J. Saurenman (WIA) with significant contributions by Michael C. Holowaty, Donald N. Smith, Thomas J. Nicarico and Larry A. Ronk of De Leuw, Cather & Company and George Paul Wilson, Armin T. Wright and Stanley M. Rosen of Wilson, Ihrig & Associates, Inc.

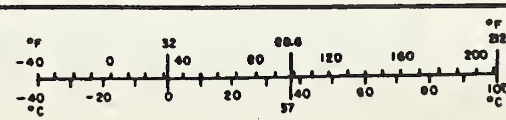
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



CONTENTS

CONTENTS (CONT'D)

CONTENTS (CONT'D)

ILLUSTRATIONS

TABLES

TABLES (CONT'D)

1. INTRODUCTION

Urban rail rapid transit noise can be a significant annoyance to both patrons and communities adjacent to transit systems. One of the primary noise sources on a rail rapid transit system is the wheel-rail interaction. At normal operating speeds for many transit vehicles, wheel-rail noise dominates both the noise radiated to the wayside and the noise inside the transit cars. Effective noise control for rail transit thus requires affordable and predictable techniques for reduction of wheel-rail noise.

The U. S. Department of Transportation (DOT), Transportation Systems Center (TSC) is the systems manager for the Urban Mass Transportation Administration (UMTA) Urban Rail Supportaing Technology Project. UMTA is sponsoring research projects to make available the technology for predictable control of acoustic noise and vibration in a form useful to present and planned urban rail systems. The ultimate goal of this research is to provide sufficient information to allow a transit system with given track and car conditions and budgetary constraints to determine the mix of available wheel-rail noise control methods which will result in the greatest overall benefit. Included in this benefit evaluation is the reduction of noise radiated to adjacent communities and the reduction of patron noise exposure.

This project is designed to provide information on both the long-term and short-term costs and effectiveness of the various noise abatement procedures if implemented on typical urban rail systems in the United States.

Although wheel-rail noise has been shown to be a major source of transit system noise, and some methods have proved to be effective in lowering wheel-rail noise, there is little documented information that can be used to evaluate the reductions that will be realized when a combination of noise abatement methods are used. Also there has been little information developed on the in-service durability of the noise reduction methods and the effects of wear on the noise levels.

The objective of this project is to document the effectiveness of four noise abatement methods and combinations of those methods, both when they are first implemented and after a significant in-service wear period. The in-service use period will develop information on both the durability of the noise abatement procedures and the effects of wear on the noise reduction realized.

The specific noise abatement techniques that are being evaluated in this study are:

a. Resilient Wheels - Wheels with a resilient material between the tire and hub that acts to damp resonant vibration of the wheel and reduce transmission of vibration to the web. Three types of resilient wheels are included in the study.

b. Damped Wheels - Standard wheels with a vibration damping treatment which acts to reduce wheel vibration.

c. Wheel Truing - Grinding or machining the wheel tire surfaces to a desired degree of smoothness to reduce the non-uniformities or roughness of the running surface which is created during operation.

d. Rail Grinding - Grinding the running rail to eliminate rail running surface roughness created by the passage of trains.

This is the third report of the study; the first two interim reports covered the Experimental Design and the Test and Evaluation Plan for the program. Included in this report are the analysis of the acoustic testing in Test Phases I, II, and III, the preliminary analysis of the cost data, and a summary of the survey of manufacturers of noise control equipment and other transit systems.

This project is concerned with not only the acoustical evaluation of the four noise abatement methods, but also with the costs of the methods and the combination of the acoustical and cost data to determine optimum combinations of abatement techniques for specific conditions. The study can be logically split into three separate sections as summarized below:

1. Evaluation of acoustical effectiveness of the noise control techniques.
2. Evaluation of the incremental costs associated with implementation of the noise control methods.
3. Combination of the cost and acoustical evaluations into a cost-benefit methodology to allow assessement of the optimum implementation of the noise abatement techniques.

In general, the testing procedure consists of measuring noise generated by test trains on the Market-Frankford Line of the Southeastern Pennsylvania Transportation Authority transit system and then comparing the differences associated with the various possible combinations of the four noise control

techniques on the different track configurations. An example of the type of information this study will provide is whether certain wheels afford a significant reduction in noise on one particular type of track, but are ineffective on others.

A cost analysis is also being performed to investigate the relationship between noise reduction and costs over the immediate and long term. Cost data relating to each of the noise control methods is being collected, and a survey of existing and soon to be operating systems is being conducted to obtain data concerning any experiences they may have had with four noise control methods being evaluated. The primary source of information on the costs of each of the noise control methods is the observaiton and analysis of SEPTA operations and costs during the test phase of this study.

To optimize the benefits from the proposed noise control methods, other factors, such as ease of implementation, longevity, and required maintenance, are also being taken into consideration.

Primary correlation will take place at the end of the project when the acoustical effectiveness and life expectancy of the measures will be weighed against the costs and problems associated with use of those methods. The final report will include a cost versus benefit analysis of the various noise control methods using the date developed in this study.

The test plan for the acoustical measurements was organized into the following six sequential phases:

PHASE I: Verify noise measurement and reduction procedure; establish variation between test and control track sections; document noise levels produced by new and worn standard wheels on worn

and ground rail; investigate differences between new and trued standeard wheels.

PHASE II: Evaluate noise characteristics of new resilient and damped wheels on all types of track.

PHASE III: Evaluate progress of wheel and rail wear with profilometer and abbreviated noise measurement program after approximately six months of wear.

PHASE IV: After an aging period of approximately one year from the end of Phase I, evaluate all combinations of worn wheel and worn rail.

PHASE V: Evaluate noise of worn wheels on newly-ground rail.

PHASE VI: Evaluate noise of trued wheels on newly ground rail.

Events which have occurred during the in-service wear period have resulted in necessary and unavoidable changes in the test plans for Phases II, III, IV, V, and VI as discussed in this report.

The acoustic measurements are being taken at the following track sections, all located on the Market Street section of the SEPTA system:

a. Tangent welded track on ballasted, elevated structure. (TW)

b. Tangent jointed track on ballasted, elevated structure. (TJ)

c. Tangent jointed track in a ballasted, elevated station. (ELESTN)

d. Swith frog on ballasted, elevated structure. (FROG)

e. Short radius curve, ballasted track at grade. (TURN)

f. Tangent welded track in subway. (SUB 1)

g. Tangent jointed track in subway. (SUB 2)

h. Tangent welded track in subway station. (SUB 3)

Locations and details of the test sections for the acoustic measurements are shown in Figures 1-1 through 1-6. As a result of suggestions made by the American Public Transit Association (APTA) Industry Advisory Board and through volunteer effort by Port Authority of New York and New Jersey (PANYNJ) personnel, rail and structure vibration levels were also measured at the welded track test sections in the subway and on the ballasted elevated structure.

The following paragraphs present a description of each rail test section and a general description of the tests and objectives at each section.

TW TEST SECTION - This test section is of timber tie and ballast construction with field welded rails, located on elevated structure between the 60th and 63rd Street Stations. The section is divided into two 300-ft segments; Control and Test. The Control segment is to remain unaltered except as affected by normal wear throughout the Test program while the Test segment rails are to be ground at the beginning and end of the in-service wear period for before-after tests. The purpose of the noise tests before and after rail grinding is to provide a direct comparison of the effect of rail grinding on the wayside and car interior noise both at the beginning and the end of the in-service wear period. As it has turned out, car interior and wayside noise

measurements were performed during the interim measurements of Phase III because, at the time, it appeared that the resilient wheels would be taken out of service. In both Phase I and Phase II, measurements of vibration of the rail and structure were performed simultaneously with the noise measurements.

<u>TJ TEST SECTION</u> - This test section is of timber tie and ballast construction with jointed rail, located on the elevated structure between the 56th and 60th Street Stations. The section is divided into three 300 ft segments; A, B and Control. The Control segment will remain as is throughout the test program. During the Phase I measurements, the joint bars of Segment B were changed and before/after noise tests were performed with the standard wheel cars to determine if the improved joint alignment, following changing the joint bars, reduced wayside car interior noise levels. During Phase II, the rails of both Segment A and Segment B were ground and before/after measurements were made with all five test trains. Car interior noise tests were performed on the TJ test section during the interim measurements of Phase III. These rail segments will again be tested before and after rail grinding during the Phases IV, V, and VI tests.

<u>ELESTN TEST SECTION</u> - This section is composed of timber tie and ballast track with jointed rails and is located on the elevated structure at the 63rd Street Station. This section will be used to determine if there is any noticeable difference in noise radiation to the station platform by the various test wheels.

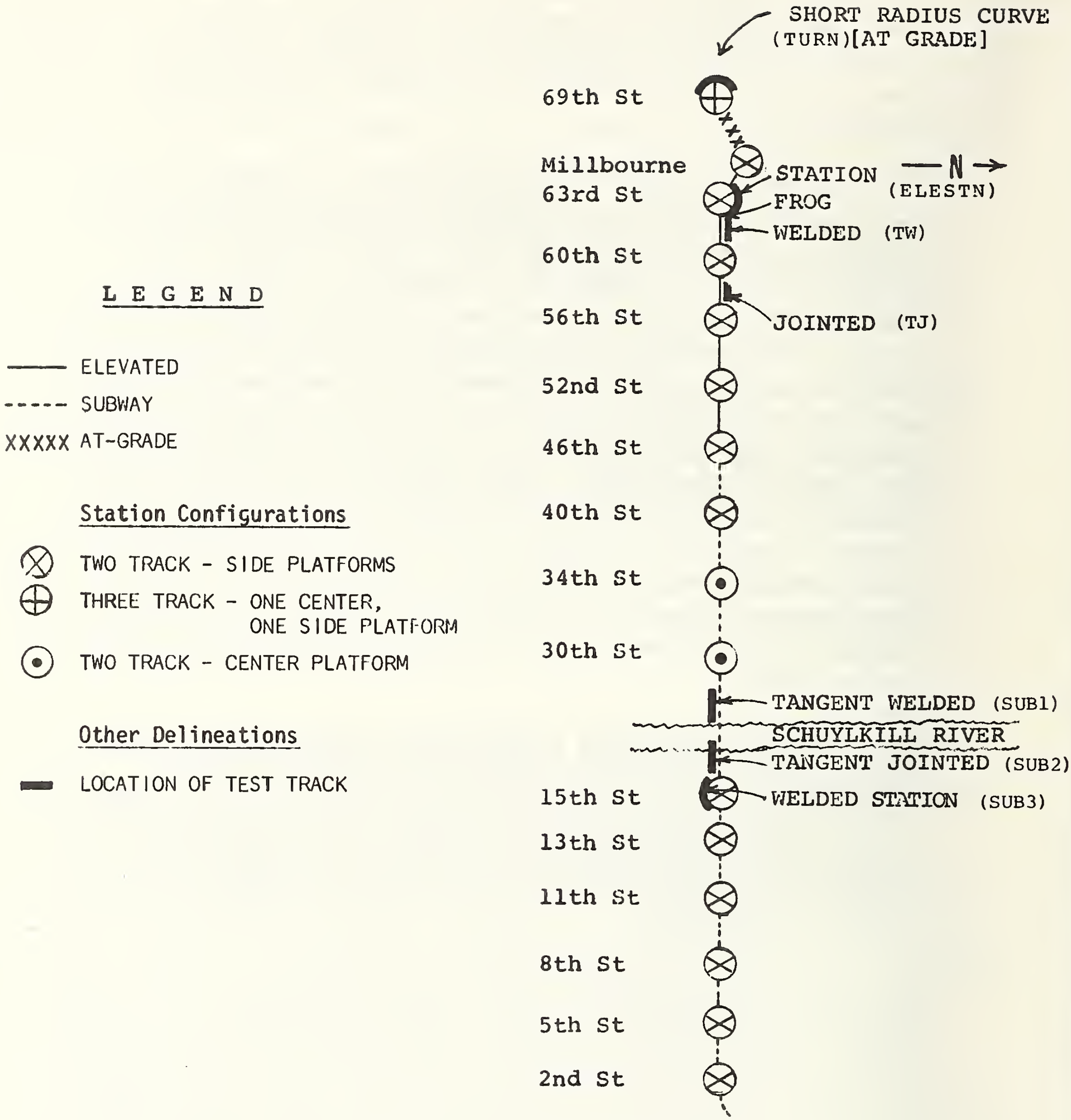


Figure 1-1. SCHEMATIC OF MARKET STREET SUBWAY ELEVATED SYSTEM

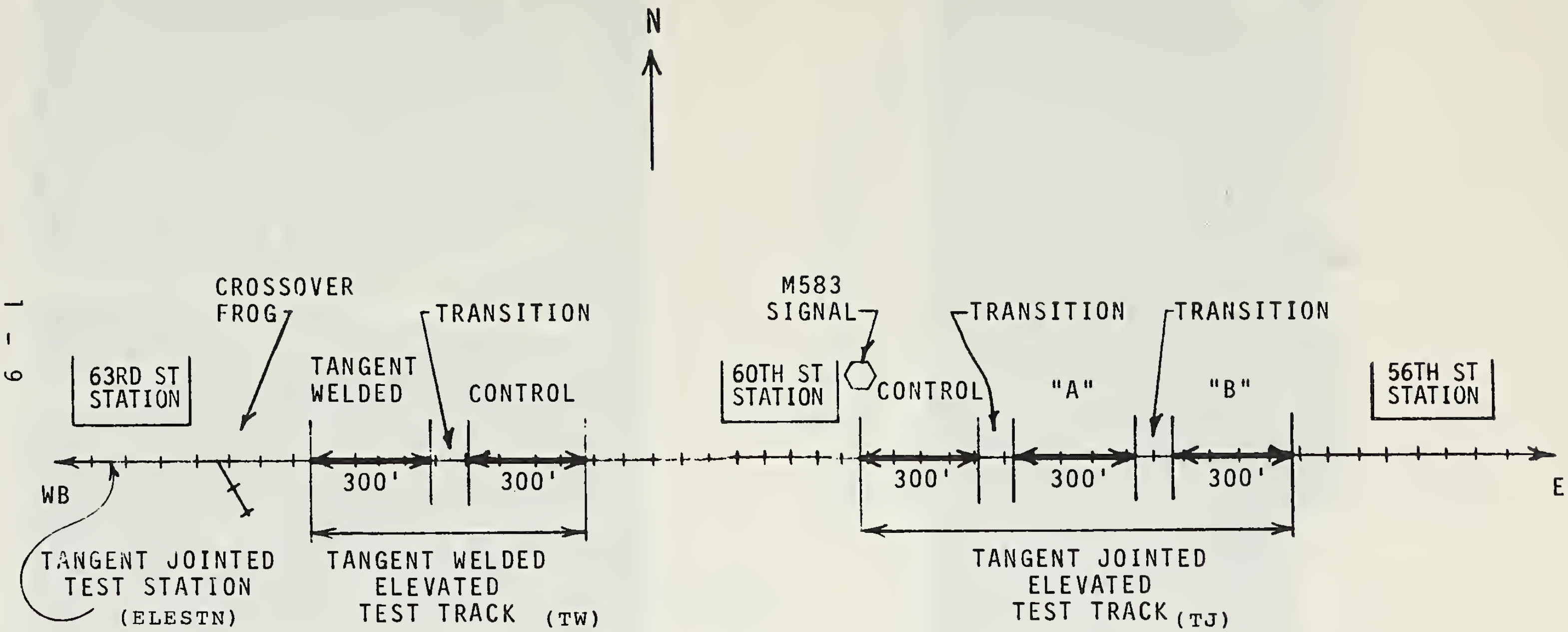
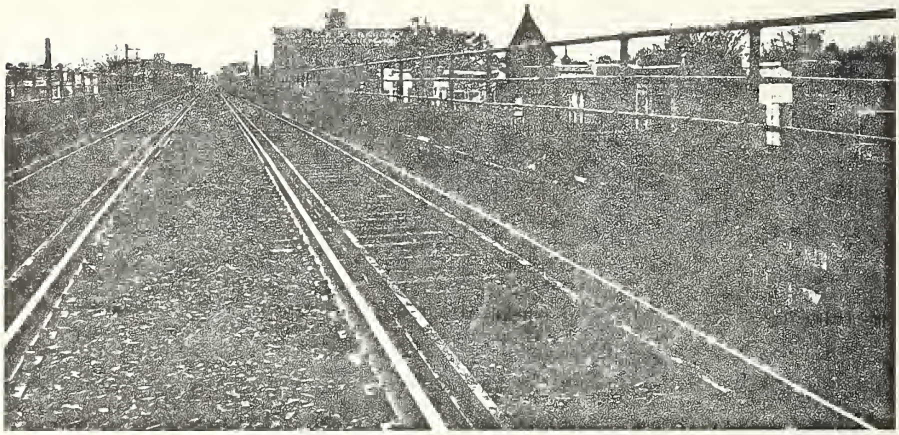
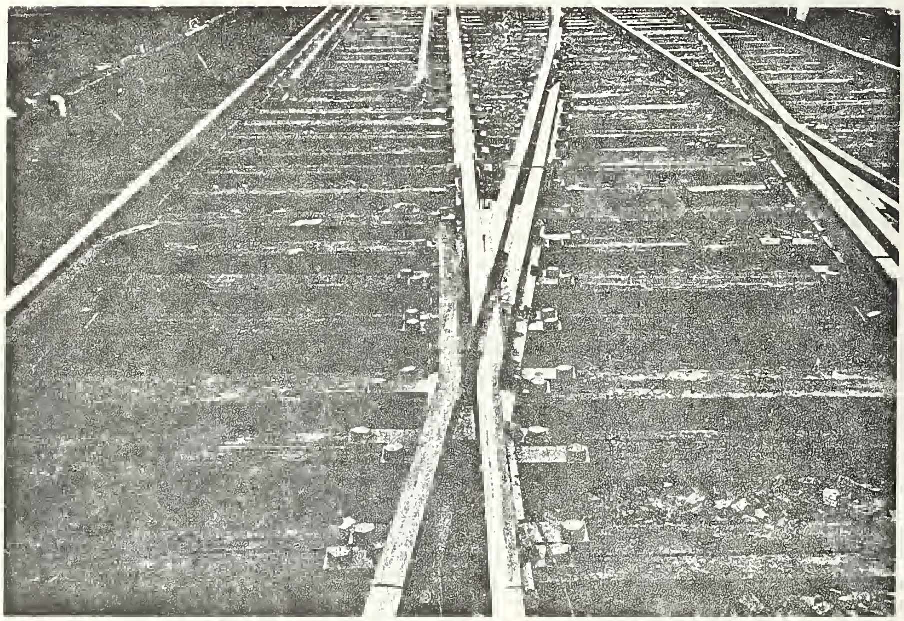


Figure 1.2. ELEVATED STRUCTURE TEST TRACK



TYPICAL VIEW OF BALLASTED DECK
OF ELEVATED STRUCTURE



CROSSOVER FROG ON ELEVATED STRUCTURE

Figure 1-3. PHOTOGRAPHS OF THE MARKET STREET ELEVATED STRUCTURE

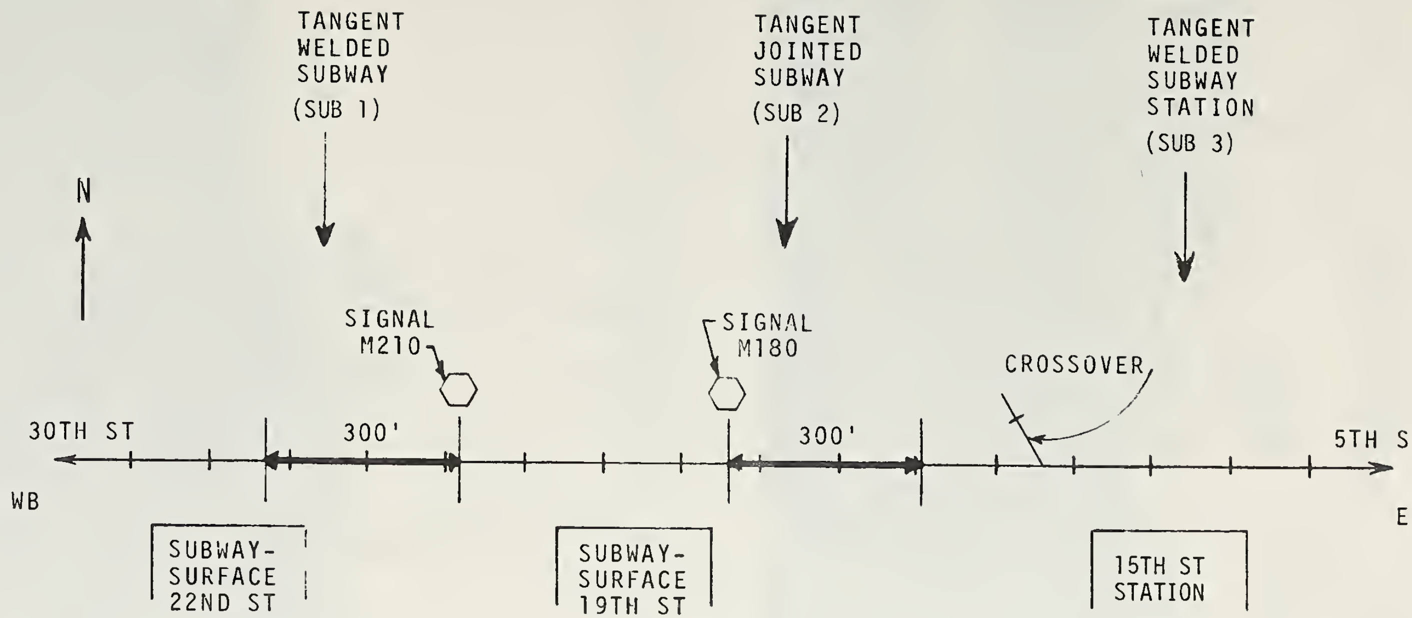


Figure 1-4. SUBWAY TEST TRACK

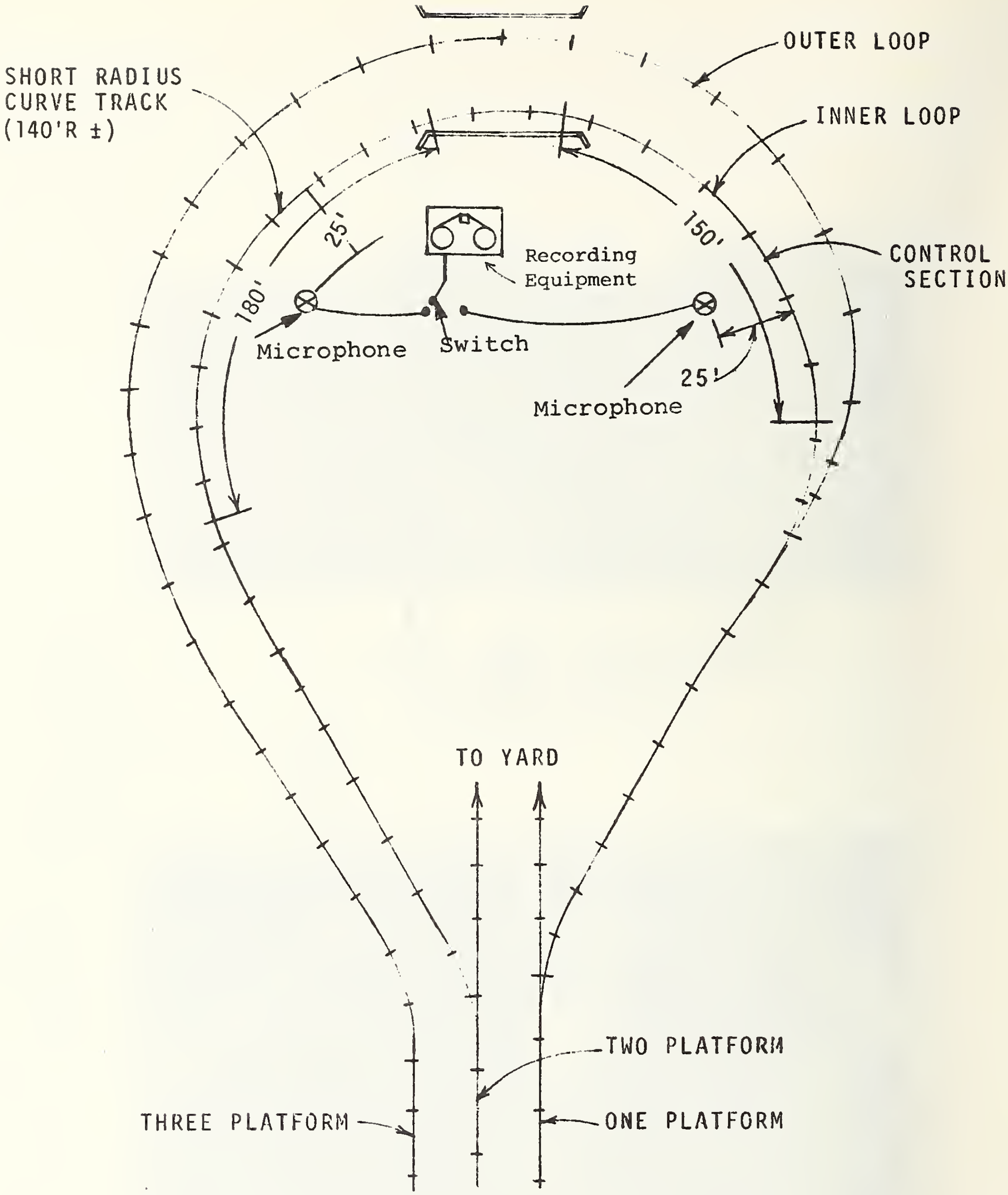


Figure 1-5. SKETCH OF SHORT RADIUS CURVE (AT GRADE) TEST TRACK-INSIDE TURNAROUND TRACK AT 69TH STREET STATION

TRANSITION BETWEEN TEST SECTION
AND CONTROL SECTION OCCURS AT BRIDGE.
THE CONTROL SECTION IS IN THE FOREGROUND.

THE TEST SECTION IS IN THE FOREGROUND

Figure 1-6. PHOTOGRAPHS OF 69TH STREET TURNAROUND

FROG TEST SECTION - This section is the crossover between the 60th and 63rd Street Station. The crossover is of timber tie and ballast construction with jointed rails and is located on aerial structure. The purpose of the frog test section is to determine the differences in car interior and wayside noise from rail discontinuities for the various trains with the various wheels and wheel conditions included in the test series. The testing was performed with all five test trains during the Phase II test series.

TURN TEST SECTION - This section is composed of timber tie and ballasted track at-grade construction with jointed low rail, welded high rail and a radius of curvature of approximately 140 feet. The track is the inside turnaround track at the 69th Street Station. The track is divided into two segments; Control and Test. The test section rails are to be ground at several intervals during the test program with the Control section just subjected to normal wear. The purpose of the tests is to determine the effectiveness of the various types of resilient wheels in reducing wheel squeal and to determine the effects on car interior and wayside noise of rail grinding for before/after tests, both at the beginnning and at the end of the in-service wear period. For this test track, the Phase III interim measurements also included both car interior and wayside noise.

SUB 1 TEST SECTION - This section is composed of field welded rail fastened to timber half ties embedded in the concrete invert of the subway structure. The section is located just east of the 22nd Street Subway-Surface Station and is approximately 300 feet long. The tests at this section include car interior noise measurements and measurements of rail and ground vibration before and after grinding of the rail. The tests are designed to determine the effects of rail grinding on car interior noise at the beginning and the end of the in-service

wear period. Tests on this test section were also performed at the time of the interior measurements. Although there is an insulated joint located near the middle of this test section, the data analysis procedures avoid the effects of the joint.

SUB 2 TEST SECTION - This section is similar to SUB 1 except that the rail is jointed. The section is located just east of the 19th Street Subway Surface Station and is approximately 300-ft long. Only car interior noise measurements are taken at this location and the purpose is to determine the effects of rail grinding on wheel-rail noise, both at the beginning and the end of the in-service wear period. This section was also included in the interim measurement series.

SUB 3 TEST SECTION - This section is similar to SUB 2 except that it is located in the 15th Street Subway Station. At this test section, measurements of noise on the station platform are made to determine the noise levels on the platform before and after grinding at the beginning and end of the in-service wear period.

For all of the above outlined rail test sections, the tests for each section include all five test trains to provide information on wheel-rail noise characteristics with various types of wheels and wheel conditions. The tests were arranged to evaluate the wheel-rail noise characteristics with the resilient wheels in new and worn condition and for the standard wheels in new, trued and worn condition. The following paragraphs indicated the wheel sets included in the test series for this part of the evaluation.

WORN STANDARD WHEELS - This set of wheels is the standard SEPTA solid wheel configuration which will be left as is, (i.e., only subjected to normal wear), throughout the test period. At the beginning of the tests, these wheels had approximately 1 year in-service wear. This set of wheels provides reference data that identifies changes of noise level due to uncontrolled parameters such as weather, etc.

NEW STANDARD WHEELS - This set of wheels, standard SEPTA solid steel wheels in new condition with lathe turned running surface, is intended to provide data for new wheel or lathe trued conditon. Further, in the Phase I testing, this set of wheels was trued, using the SEPTA milling cutter type truing machine, for direct comparison of the results with wheels trued by lathe turning and wheels trued by the milling cutter procedure.

RESILIENT WHEELS - Three different types of resilient wheels are included in the tests. The tests have been designed to indicate the effects on noise and vibration by using resilient wheels. Tests are to be performed at the beginning, at the mid-point, and at the end of the wear period, hence with the wheels in new and worn condition. The wheels tested included Acousta Flex manufactured by Standard Steel, Penn-Machine Bochum supplied by Penn Machine Company and manufactured by Bochumer Verin A.G. of West Germany, and SAB type resilient wheels manufactured by Svenska Aktiebolaget Bromsregulator of Sweden.

DAMPED WHEELS - It was intended that the testing include an evaluation of the effectiveness of wheel damping. However, the technique submitted was unacceptable to SEPTA personnel resulting in the omission of damped wheels from the first and mid-series tests. An effort is being made to include ring-damped wheels in the final test series.

Parallel to the performance of the acoustic testing, information was collected on the cost of the noise control methods and other factors that relate to the implementation of the methods. The primary source of data on the total cost (initial, operating and maintenance) for each of the noise control methods is observation and analysis of SEPTA operations and costs during the test phase of the program.

To supplement the data available from SEPTA, an extensive survey of other North American transit systems has been carried out. The purpose of the program was to determine specific experiences of the transit systmes with the noise control methods including information such as labor, time and costs associated with, and operational experience with rail grinding, wheel truing and resilient wheels. As most transit systems presently have wheel truing and rail grinding equipment, a major purpose of the survey was to collect information on the existing programs. Typical information collected includes types of equipment, criteria for deciding when to grind rail and true wheels, labor requirements and cost of the equipment

The survey of transit systems was divided into two parts - first a preliminary survey to collect information on the equipment used by the transit systems and second an indepth questionnaire to determine the cost breakdowns for labor and equipment for rail grinding and wheel truing. The survey also included gathering any other information pertinent to the noise control methods. To supplement the information about the experience of the transit systems with the noise control methods, the survey has gathered information about each system's operations, the equipment operated, and the physical layout of the system.

2. SUMMARY AND CONCLUSIONS

The in-service performance and cost study of methods for reducing urban rail system noise has progressed to approximately mid-point of the program. The first three phases of six phases of acoustic measurements have been completed and the gathering of the cost data from the transit properites and manufacturers has been completed. This interim report presents the results from the first three phases of the acoustic testing and the information gathered from the transit properties and manufacturers on the costs associated with the four noise reduction methods under study - rail grinding, wheel truing, damped wheels and resilient wheels.

Because of the deletion of the original submission for damped wheels to be used in the study (visco-elastic rim dampers), the acoustic test results for the first three phases comprise data only from rail grinding, wheel truing and resilient wheels. A second type of damped wheel (ring-damped wheels) will be included in the final three phases of the acoustic testing. The cost data and product information acquired includes data on all four types of noise control procedures.

2.1 ACOUSTIC TEST RESULTS

The basic data obtained from the acoustic tests were the change in noise level at the various test tracks resulting from rail grinding, wheel truing, resilient wheels, and the combination of rail grinding with wheel truing or resilient wheels. The test tracks included tangent-welded ballast and tie track, tangent-jointed ballast and tie track, short radius curve on ballast and tie, subway tracks with both jointed and welded rail and station platforms with both jointed and

welded rail. All welded rail on SEPTA is field welded; there is no shop welded rail. The results for all of these combinations of wheel and rail conditions are presented and analyzed in the results section of this interim report.

The results of the noise level measurements lead to the following general observations and conclusions.

- Propulsion System Noise:

  Tests of the propulsion equipment noise as a component of the total noise from the SEPTA transit cars indicate that the propulsion equipment noise is only 4 to 5 dBA below the total noise for trains operating on tangent welded track. Therefore, *the propulsion equipment noise limits the ability to reduce overall noise from the SEPTA trains through reduction of wheel-rail noise.* This leads to the conclusion that there may have been greater reduction of wheel-rail noise than was observed for the reduction of total train noise measured on SEPTA and reported herein. Tests on other transit systems[1,2,3], that achieved greater reductions of overall wayside and car interior noise levels tend to support this conclusion.

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[1] "Noise Levels from Operations of CTA Rail Transit Cars", prepared for Chicago Transit Authority by Wilson, Ihrig & Associates, Inc., May, 1971.

[2] "Final Report on BART Prototype Car 107 Noise Tests", prepared for Bay Area Rapid Transit District by Wilson, Ihrig & Associates, Inc., June 1972.

[3] R. Lotz, "Railroad and Rail Transit Noise Sources," Journal of Sound and Vibration, Vol. 51, No. 3, pp. 319 -336, 1977.

- Rail Grinding:
  a. On tangent welded track the rail grinding reduced noise levels at the wayside, on the station platform and for the car interior in subway, but did not produce reduction in the car interior for the surface ballast and tie track. On the tangent-jointed track, grinding of the rail produced reduction of both wayside and car interior noise levels. In all cases, the reductions observed from the rail grinding were small, on the order of 2 to 4 dBA for wayside noise and 2 dBA or less for in-car noise.

  b. For the curved track, grinding of the rail resulted in increased squeal levels by 2 to 4 dBA compared to the worn rail condition.

- Wheel Truing:
  1. None of the wheels contained visible flat spots prior to truing.

  2. For tangent track, truing of the standard wheels with the SEPTA milling cutter type truer resulted in reduced noise levels (1 to 2 dBA) compared to the worn wheels. The lathe-turned or new-condition wheels were found to be 2 to 5 dBA quieter than the worn wheels.

  3. On curved track, the new lathe-turned wheels produced squeal of lower levels (3 to 5dBA), but with similar character to that produced by the worn standard wheels. The milling cutter-trued wheels produced similar squeal levels to the

worn standard wheels but with additional squeal frequencies indicating a change in the wheel-rail contact condition for the trued wheels, at least before significant wear had taken place.

- Resilient Wheels:

  a. For all of the test conditions except the subway station platform noise the resilient wheels produced noise levels either comparable to or lower than those produced by the standard wheels in the new or trued condition. These differences were small for all the test tracks except the short radius curve. At the short radius curve the resilient wheels produced spectacular reduction of the squeal noise.

  b. On the tangent welded track the wayside and car interior noise with the resilient wheels was 0 to 2 dBA less that with the new or trued wheels and 2 to 4 dBA less that with the worn wheels, On the tangent-jointed track, similar results were observed except that the reductions were more consistent than found for the welded rail.

  c. The resilient wheels all resulted in dramatic reduction of high pitched wheel squeal on the short radius turn. Reductions of 25 to 30 dB were found in all cases for the 8 kHz component of the squeal at the wayside. The Acousta Flex

and Bochum wheels essentially eliminated all squeal, however, the SAB wheels added a component of squeal at about 1200 Hz, which limited the overall A-weighted noise level reduction to about 8 dBA at the wayside and 1 dBA in the car interior. For the other two sets of wheels, the reduction of overall noise level compared to the standard wheels was about 12 dBA at the wayside and 4 dBA in the car interior.

- Combined Results:
  1. The results for the test conditions which comprise a combination of rail grinding, wheel truing, and resilient wheels, when compared to the data with the worn standard wheels on unground rail, did show some increase in noise reduction compared to the effects on the individual noise reduction procedures. However, the noise reductions obtained were not directly additive. That is, if rail grinding gave 2 dBA reduction and resilient wheels gave a 3 dBA reduction, the total for the two was not 5 dBA, but was typically only 4 dBA.
  2. The overall results indicated that, in comparison with the worn wheels on worn rail, trued wheels on ground rail gave about 4 dBA reduction on jointed rail and negligible reduction on welded rails for wayside noise, but about 2 to 4 dBA reduction for car interior noise for all configurations.

3. The resilient wheels on ground rail (compared to worn standard wheels on worn rail) in general gave 2 to 6 dBA overall noise reduction for wayside noise and car interior noise on both the tangent welded and tangent-jointed rail and produced dramatic reduction of squeal noise on curved track as indicated above.

- Wheel and Rail Roughness:

  The measurements which were obtained of the roughness of the wheel surface, while correlating well with other similar measurements, did not produce data which showed significant correlation or even any direct relation to the overall noise. To some degree, the contribution of the propulsion noise to the overall noise level may have obscured any correlation. Thus, no conclusive information was obtained from the efforts at measuring the unloaded surface roughness of the wheels. Efforts to measure the rail roughness were unsuccessful.

- Welded and Jointed Track:

  The wayside and car interior sound levels produced by cars with standard wheels were approximately 6 dBA and 3 dBA lower on tangent welded tie and ballast track than on tangent jointed tie and ballast track. The cars with resilient wheels produced wayside and car interior noise levels approximately 4 dBA lower on welded track.

- Summary:

  The overall conclusion from the acoustic tests is that all of the noise reduction procedures produced some noise reduction for most of the test conditions. The nine months wear period for the third phase tests showed some increase of noise level after the wear period for some conditions and showed no increase or decrease in noise for other conditions. However, in all cases except for the wheel squeal noise reduction by resilient wheels, the noise level reduction were small-not exceeding 5 or 6 dBA total for the most favorable results. As discussed in Section 4 - 1, *the contribution of propulsion equipment noise to the overall noise level limited the reduction that could be observed to 4 to 5 dBA on welded track and 6 to 8 dBA on jointed track.* In most cases, the reductions observed were statistically significant, but with the exception of wheel squeal or curves, the reductions were so small as to not be of large value in terms of reduced noise to patrons and neighbors of the transit system. However, reductions of 2 or 3 dBA could be very important in trying to meet a specified noise level or regulation. It should be noted that because of the conditions imposed by the SEPTA system rail and cars and because of the contribution of the vehicle propulsion system to the total wayside and in-car noise, these results

and conclusions should not be generalized as applicable to wheel-rail noise reduction on other transit systems or vehicles. This generalization will be developed in the final report.

2.2 ECONOMIC DATA RESULTS

North American Rapid Transit Systems utilizing steel wheel technology were solicited concerning their experience with resilient and damped wheels, wheel truing, and rail grinding. In addition, detailed information was requested concerning the techniques, costs, and equipment associated with wheel changing, wheel maintenance, wheel truing, and rail grinding. The information was solicited in three questionnaires sent to each system and in general was followed by an on-site visit and personal interviews with operating, maintenance, and management employees.

At present, nearly complete information has been received from the Chicago Transit Authority (CTA), Greater Cleveland Regional Transit Authority (GRCTA), Massachusettes Bay Transit Authority (MBTA), Port Authority Transportation Company (PATCO), Port Authority Trans Hudson Corporation (PATH), Southeastern Pennsylvania Transportation Authority (SEPTA), and the Washington Metropolitan Area Transit Authority (WMATA).

Less detailed information has been received from the Bay Area Rapid Transit District (BART), New York City Transit Authority (NYCTA), and the Toronto Transit Commission (TTC). It is planned that information presently outstanding will be gathered and analyzed prior to the completion of the project.

Information was also obtained from equipment and wheel manufacturers concerning the purchase costs, maintenance costs, and projected service lives for wheel truing and rail grinding equipment and for resilient and solid steel wheels. All costs contained in this report are in 1977 dollars unless otherwise noted.

Life-cycle cost equations were developed for resilient wheels, steel wheels, wheel truing, and rail grinding. These equations calculate the present value of the life-cycle costs for each element and consider initial costs, maintenance costs, operations costs, and projected service lives. Sensitivity analyses were performed to determine the effect of variable date on the results produced by the equations. The life-cycle equations can be used to calculate the present value of costs for employing each of the noise abatement techniques on any rapid transit system.

The majority of the cost analysis will be performed and the correlation between economic and acoustic effectiveness determined after the final stages of field testing and the completion of the data gathering process. Initial findings concerning the cost of the noise abatement techniques on SPETA are as follows.

- Wheels:
  a. The life-cycle cost analysis showed that a car set of SAB resilient wheels will cost approximately 1.6 times the cost of a car set of solid steel wheels over the life span of the SAB wheels, assuming that the wear rate for the SAB and solid steel wheels is the same.

  b. The life cycle cost analysis is not sensitive to maintenance and inspection costs but is dependent upon initial costs and length of service life. One manufacturer claims that resilient wheels wear at a 40 percent slower rate than solid steel wheels. If correct, this increased life would have a marked effect on the present value of the life-cycle costs. For example, if the service life of a SAB tire is increased from seven to ten years, the ratic of the life-cycle

costs decreases from 1.6:1 to 1.2:1.

c. It had been planned that the service life of the resilient wheels would be determined during the field testing program. Unfortunately, all resilient wheels were removed from services prior to a sufficient amount of mileage being accrued by the wheels to allow significant wear measurements to be made.

- Wheel Truing:
  1. The cost of wheel truing varies greatly depending upon the type of equipment used in the wheel truing process. Wheel truing one car set of wheels on SEPTA's Broad Street Line, performed on an above floor lathe, requires 80 man hours of effort at a cost of $775; whereas, wheel truing one car-set of wheels on the Market Frankford Line, performed on an underfloor milling machine, requires only 8.5 man hours of effort at a cost of $85. The purchase price of above floor and underfloor equipment is similar, however.
  2. The large difference in cost for wheel truing is also found on the other transit properties and points out the great advantage of the underfloor method of wheel truing.

- Rail Grinding:

  SEPTA is one of five North American transit properties owning a rail grinding train. Four systems do not utilize rail grinding. The Port Authority Transit Corporation (PATCO) contracts for rail grinding services on a bi-annual basis. The systems owning rail-grinding equipment are those which have a high incidence of rail corrugations.

2.3 MODIFICATIONS TO THE TEST PROGRAM

A number of changes have been made to the project during the course of the first three phases of testing. These changes are as follows:

a. The test program was to have included the testing of two-car set of viscoelastic-damped wheels. Upon receiving the dampers, SEPTA decided not to allow them to be placed in service as there was doubt concerning the ability of the dampers to remain in place under operating conditions. Subsequently, the testing of the viscoelastic-damped wheels was dropped from the program.

b. The test program has been expanded to include the testing of a two-car set of steel ring damped wheels. The wheels, somewhat similar to those being provided to the CTA on their new 2400 series cars, will be included in test Phases IV, V, and VI.

c. Problems have been experienced with all three types of resilient wheels; and subsequently, all resilient wheels have been removed from the test program. The Acousta-Flex wheels were removed after a bonding failure occurred, which allowed the tire of one wheel to rotate approximately 120° with respect to the wheel center. The Bochum wheels were removed from the program after a dynamic brake failure on one of the Bochum cars had required the exclusive use of the tread brake system. The temperatures of several of the wheels

increased considerably from the tread-brake application and ultimately two of the rubber block inserts on one of the wheels experienced damage. The SAB wheels were removed from the program after two of the wheels had suffered severe damage from overheating caused by the application of the hand brake while the car was in revenue service. None of the wheel failures resulted in any mishaps during train operations.

3. TESTING PROGRAM

3.1 PHASE I TESTS

As discussed in the Test and Evaluation Plan,* the purposes of the Phase I tests were to verify the data acquisition and reduction methodology, to establish the noise baseline for standard conditions, to document noise characteristics of control cars and control tracks, and to document noise levels produced by new, worn, and trued standard wheels on worn and ground rails. This phase was divided into three main sets of tests with a preliminary set of tests for investigating data acquisition procedures and obtaining data on SEPTA car propulsion machinery noise levels.

During the preliminary tests, measurements were made of the noise from the transit-car propulsion equipment with the cars on blocks and the wheels freely spinning. Also, preliminary wayside and in-car measurements were accomplished to both check the data acquisition procedures for appropriateness and to obtain preliminary data for use in further planning of the main test series.

In test Phase IA, the worn and new standard wheel sets were tested on the test and control sections of the TW, TJ, and TURN test tracks. Both wayside and car interior data were collected. In addition, the Phase IA tests were used to verify the applicability and efficiency of the methods that had been set up to collect and reduce the acoustic data.

Following the Phase IA tests, the rails on the entire TURN section and TW test section were ground. In addition, new joint bars were placed in the TJ Test Section B. Phase IB tests were then conducted.

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*Hugh J. Saurenman and Michael C. Holowaty, "In Service Performance and Costs of Methods to Control Urban Rail System Noise - Test and Evaluation Plan, "Report No. UMTA-MA-06-0025-77-10, April 1977. (NTIS No. PB 272 - 521).

The Phase IB tests included testing both sets of standard wheels on the TW, TURN and SUB test tracks. Following Phase IB, the new standard wheels were trued. The Phase IC tests included the trued standard wheels and single cars with the worn standard wheels. The single car tests were performed to give a basis for relating noise from 1-car trains to 2-car trains, so that if a failure of one car of a 2-car train forced its removal from testing, data collected from the remaining car could still be used.

The purpose of the tests in Phase IC with the trued standard wheels was to establish if there is any significant difference existing between the noise generating characteristics of new lathe-turned wheels and wheels that had been trued with the SEPTA milling machine wheel truer.

In Phase IC, extra wayside measurements were taken on the TW test track at a distance of 15 m (50 ft) from the test track. All other wayside measurements were taken at a distance of 7.5 m (25 ft) from the test tracks. The extra measurements, which will be presented in the final report, will aid in relating the measurements taken at 7.5 m from the track to levels at greater distances. Most previous data for transit train wayside noise is for 15 m from the track. Therefore, comparison data was needed to give a firm basis for converting the data to noise levels at 15 m.

The Phase I Test Program was carried out as planned with the exception of the rail-grinding program. In setting up the rail-grinding equipment, the grinding train was operated over the complete TURN test track (test as well as control sections), thereby eliminating the control aspect of the control section.

The worn standard steel wheels were placed on single unit cars 613 and 623 and the new standard steel wheels were placed on married pair cars 755 and 756.

The Phase IA test measurements were taken on the new and worn standard wheel trains during the week of July 12, 1976. Interior and wayside acoustic measurements were taken at the TURN, TW and TJ test tracks, In addition, rail and structure vibration measurements were taken by PANYNJ personnel at the TW test track. The PANYNJ data will be presented in the final report.

Rail grinding of the TURN and TW test tracks was performed after completing the Phase IA measurements. SEPTA personnel, using their Speno grinding train with 24 abrasive grinding wheels, carried out the work the first week of August. Inadvertently the previous week, in setting up the equipment, the grinding crew made 39 passes over the complete TURN test track (test as well as control sections).

Twenty additional passes were made on the test segments of the TURN and TW sections.

The low rail on the TURN track was deeply corrugated - depth of .045 in. (.114 cm), wave length 12 in. (30.480 cm). The grinding reduced the corrugation depth to a magnitude of .006 in. to .010 in. (.152 to .254 mm). When the age and wear of the rail were considered, the total removal of the corrugations was not considered feasible. The high rail had been recently renewed with welded rail and most of the welds were high and the crown effect was reduced a similar amount. The TW test track had no measurable corrugations, but most welds also were high. Rail is field welded on SEPTA.

For the TJ test track, in an attempt to align the joints, new joint bars were installed on the TJ test segment B. The joint bars on this rail, initially laid in the early 1950's, were worn and were allowing the rail ends to move relative

to each other as a train passed over, as well as resulting in the rail ends not being the same elevation when a train was not present. Measurements were made at the locations shown in Figure 3-1 before and after installing the new joint bars. Table 3-1 presents the results of these measurements. The measurements were made by placing an 18 in. (45.72 cm) long steel straight edge on the head of the rail and measuring the gap between the straight edge and the low rail with a taper gauge.

The Phase IB test measurements were taken with the new and worn standard steel wheel trains the week of August 15, 1976. Car interior and wayside noise measurements were taken on the TURN, TW and TJ test sections to evaluate the effect of the rail grinding and alignment of joints. Car interior noise measurements were also taken in the SUB 1, 2 and 3 sections to establish the base line condition in the subway.

After completing the Phase IB tests, the new standard steel wheels were trued in preparation for the Phase IC test program. The truing operation was performed by SEPTA personnel with the underfloor truing machine at the 69th Street Shops. Wheel roughness measurements were taken on the new steel wheels both before and after truing and were also taken on the worn steel wheels.

Phase IC test measurements were made on the new and worn standard steel wheel trains the week of August 29, 1976. Car interior and exterior noise measurements were taken on the TURN and TW test sections to ascertain the effect of truing the new standard steel wheels.

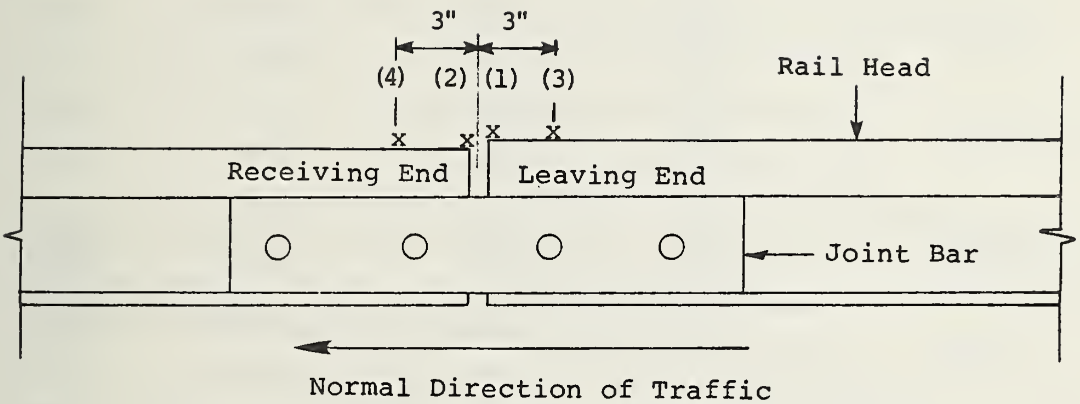


FIGURE 3.1 JOINT BAR MEASUREMENT LOCATIONS
TJ TEST SECTION, SEGMENT "B"

TABLE 3.1 RAIL END MISMATCH AND BATTER MEASUREMENTS (INCHES)
TJ TEST SECTION, SEGMENT "B"
BEFORE AND AFTER JOINT BAR INSTALLATION

JOINT LOCATION*	BEFORE INSTALLATION		AFTER INSTALLATION	
	MISMATCH+	BATTER+	MISMATCH	BATTER
1 North	.145 [1]	.110 [3]	.032	.005
	- [2]	.131 [4]	.030	.016
1 South	.049	.029	.034	.010
	.120	.101	.034	.015
2 North	.116	.070	.062	.019
	.085	.079	.034	.017
2 South	.107	.085	.020	.000
	.106	.075	.055	.0018
3 North	.089	.081	.022	.000
	.080	.075	.015	.000
3 South	.108	.118	.040	.012
	-	-	.048	.013
4 North	.109	.084	.018	.008
	.136	.100	.048	.008
4 South	.067	.046	.040	.021
	.102	.088	.050	.034
5 North	.070	.035	.048	.024
	.091	.077	.066	.037

* Locations refer to North and South rails traveling westward from 56th Street Station.

1, 2, 3, and 4 - Pertain to location of measurements as shown in Figure 3-1.

+For this exercise, mismatch is defined as the vertical distance from the bottom of an 18 inch steel straight edge placed along the center of the top of rail to the top of rail at rail end. Similary, batter is the vertical distance at 3 inches from the rail end.

3.2 PHASE II TESTS

The purpose of the Phase II tests was to evaluate and compare noise characteristics of new resilient wheels with trued and worn standard wheels on all the test sections. It had originally been planned to test three types of resilient wheels (Acousta Flex, Penn Machine Bochum and SAB) and one type of damped wheel (the visco-elastic Soundcoat wheel damping system). However, upon receiving the Soundcoat damper, SEPTA decided not to install them because of apprehension about the possiblity of the dampers becoming detached from the wheels during operations.

The resilient wheels were installed as follows:

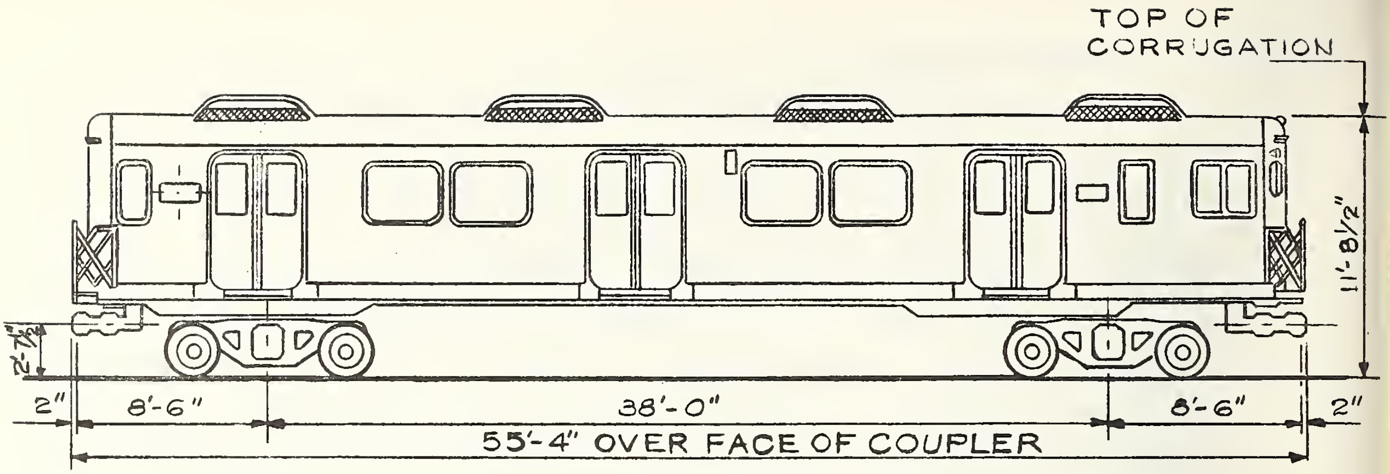
Acousta Flex - Single Unit Cars 628 and 645

Bochum - Single Unit Cars 628 and 631

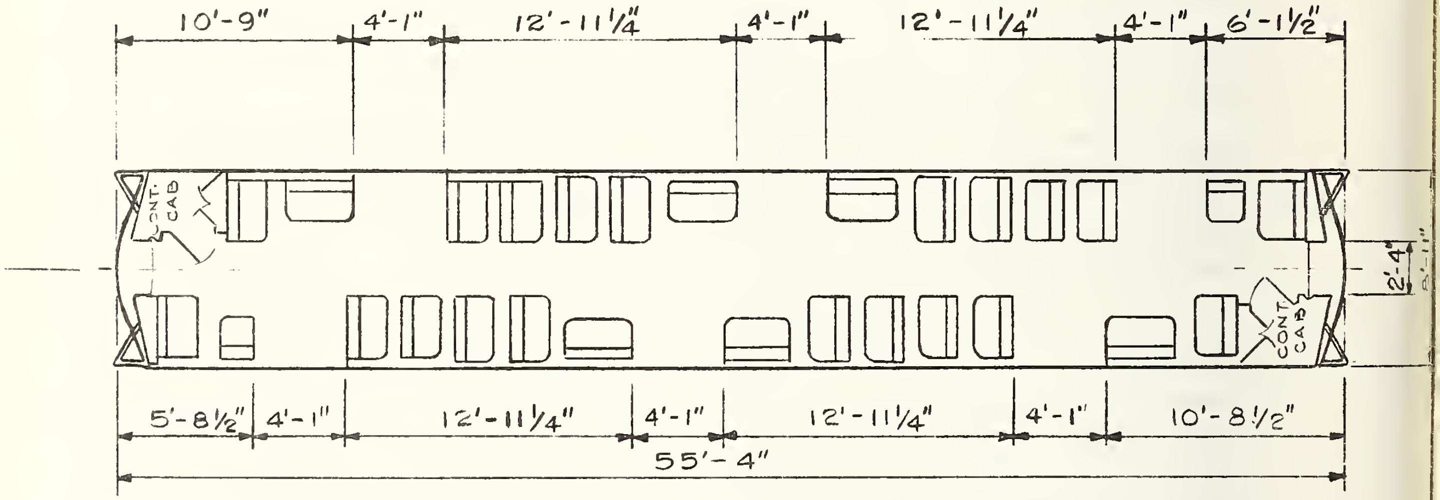
SAB - Single Unit Cars 609 and 630

Figure 3-1 illustrates a typical vehicle utilized in the test program. The cars have 28-inch diameter (71.12 cm) wheels and Adirondack trucks. Each axle is powered by a 100 hp motor manufactured by Westinghouse or General Electric.

In Phase IIA, the resilient and damped wheels were tested on the TURN, TW, TJ, SUB 1, SUB 2, SUB 3 test tracks. The Phase IIA measurements were begun the weekend of October 2, 1977. These were the first measurements made with the resilient wheels. Measurements with the resilient wheel cars only were taken Sunday morning between 30th and 5th Streets over the SUB 1, SUB 2 and SUB 3 test sections on the eastbound track. Interior measurements were taken at the SUB 1 and SUB 2 sections; ex-exterior measurements were taken at the SUB 3 section; and vibration measurements were taken by PANYNJ at the SUB 3 section; and vibration measurements were taken by PANYNJ at the SUB 1 test section. All test runs were completed within the alloted schedule.



ELEVATION "NEAR SIDE"



FLOOR PLAN

Supplier - Budd Company

Wheels - 28-inch diameter

Trucks - Adirondack

Motors - Single Units - Westinghouse Model 1454, 100 hp, one motor per axle

Married Pairs - Westinghouse Model 1454, 100 hp, one motor per axle on car 756

General Electric Model 1250, 100 hp, one motor per axle on car 755

FIGURE 3-2. SEPTA MARKET-FRANKFORD LINE VEHICLE

The testing for measurement of wheel squeal on the TURN test track in Phase II was scheduled to include the resilient wheel sets and the standard wheel sets, even though in Phase I measurements with the same test conditions had been performed with standard wheels. The measurements with the resilient wheel sets were completed. However, before the measurements of the standard wheel sets could be accomplished the tests had to be terminated because of rain. The rain lubricated the rail a sufficient amount to change the noise generation characteristics and, in fact, eliminated wheel squeal with the standard wheels. By Sunday evening/Monday morning, the rain had stopped and measurements were taken with all cars on the TW and TJ elevated test sections. Interior, exterior and vibration measurements were taken.

Following Phase IIA, test Sections A and B of the TJ test track and the entire subway test track were ground. In Phase IIB, measurements were made with all five two-car sets of wheels on the TJ, SUB 1, SUB 2, SUB 3, FROG and ELESTN test tracks. Also, between the Phase IIA and Phase IIB measurements, wheel roughness measurements were performed at the 69th Street Shop.

The rail grinder, which had to be repaired causing delay of the Phase IIB measurements, was used to grind the TJ "A" and "B" test sections on Tuesday morning, October 12. TJ "B" had previously had the joint bars replaced in July. Eighteen passes were required to insure that metal from the running surface was removed throughout the length of the test sections. In the joint areas, it was not possible to completely smooth the running surface due to the amount of joint batter that had occurred through the years. On Wednesday morning, October 13, the subway test tracks were ground. Eighteen passes were

required on the SUB 1 section, while only fourteen were needed on SUB 2 and SUB 3.

On Thursday morning, October 14, the Phase IIB tests were begun and interior and exterior noise measurements were made at the TJ test track to determine the effect of grinding. Additionally, measurements were made passing over the FROG at 63rd Street and on the 63rd Street station platform (ELESTN). This is the only Phase during which these station measurements will be made. All five sets of cars were tested. The tests were completed within the allotted time.

On Friday morning, October 15, measurements were taken on the subway test tracks. All five sets of cars were tested. Vibration measurements were taken by PANYNJ personnel at the SUB 1 Section.

3.3 PHASE III TESTS

The Phase III tests were designed to provide information on the car interior noise levels at approximately the midpoint of the wear period. The measurements were originally scheduled to be completed in April 1977, however, considerable delay was created by a strike at SEPTA. The measurements were performed on July 14, 1977. Phase III tests were originally designed to include measurements of car interior noise only on the TURN, TW, TJ, SUB 1 and SUB 2 test tracks using all five test trains. However, since some failures of the resilient wheels had occurred and since more of the wheels were scheduled to be removed from the test trains immediately following the Phase III testing, the measurements were expanded to include wayside measurements at the TW and TURN test tracks. Further, since one car of Acousta Flex wheels and one car of Bochum wheels had been removed, the remaining two cars, one with each of these types of wheels, were operated as a 2-car train during

the Phase III tests. The Phase I and Phase II results had indicated that the Acousta Flex and Penn Bochum wheels were acoustically very similar, therefore, it was thought that operation of a train with both types of wheels would give the best data under the then existing limitations and would not result in significant differences in acoustic performance for car interior noise.

Another variation in the Phase III testing program was the incorporation of car interior noise measurements with the ceiling ventilation fan dampers in both the open and closed position. The purpose of these tests was to establish the change, if any, in car interior noise level caused by having the dampers either open or closed and to determine if variations in the damper position would have a significant effect on the test results. The tests with the ventilation fan dampers in the open and closed position were performed with the worn standard wheel test train (cars 613 and 623) and on the resilient wheel test train having one car with Acousta Flex wheels and one car with Penn Bochum wheels (cars 626 and 645).

The Phase III testing program schedule called for measurement of wheel roughness and other physical parameters of the wheels such as diameter, out-of-roundness, wobble and contour. Due to the disappearance of the wheel roughness measurement equipment stored at the SEPTA shops, the wheel roughness was not measured. The other physical parameters were measured on the evening of July 13, 1977.

3.4 MAINTENANCE AND PHYSICAL MEASUREMENTS OF RAIL AND WHEELS

To obtain some indications of wheel wear and condition and rail wear and condition some physical measurements of the wheels and rails were included in the evaluation. The

measurements on the wheels included measurement of wheel diameter, measurement of out-of-roundness or eccentricity and recordings of the wheel contour. Measurements on the rails included recording of the contour of the rail head and, in the case of the jointed rail test section TJB, measurement of the offset at rail joints.

The purpose of the physical measurements of the wheels and the rails was to give some indication of the wheel and rail condition and to provide a record of the state-of-maintenance of the equipment at the time of the noise and vibration tests.

3.5 ACOUSTIC DATA ANALYSIS PROCEDURES

The acoustic data have been analyzed using a 1/3 octave real time analyzer to obtain both A-weighted and the 1/3 octave band sound levels. For consistency, during the measurements, the same equipment was used at each measurement location. A description of the acoustic equipment is contained in the Test and Evaluation Plan*. The response characteristics of the microphones used at the different measurement locations on each test track were carefully matched to optimize the accuracy of direct comparisons of the results. To improve the accuracy of comparisons between different groups of microphones, the frequency response of each system was adjusted during the data reduction process to obtain uniform frequency responses for all measurement locations.

Figure 3-3 presents typical examples of the A-weighted sound level time histories for the three principal types of measurements made: wayside noise at the turnaround, wayside noise at tangent tracks and car interior noise. The figure also indicates the times and lengths of the data samples used for the analysis.

*Hugh J. Saurenman and Michael C. Holowaty, "In-Service Performance and Costs of Methods to Control Urban Rail System Noise-Test and Evaluation Plan," Report No. UMTA-MA-06-0025-77-10, April 1977. (NTIS No. PB 272-521).

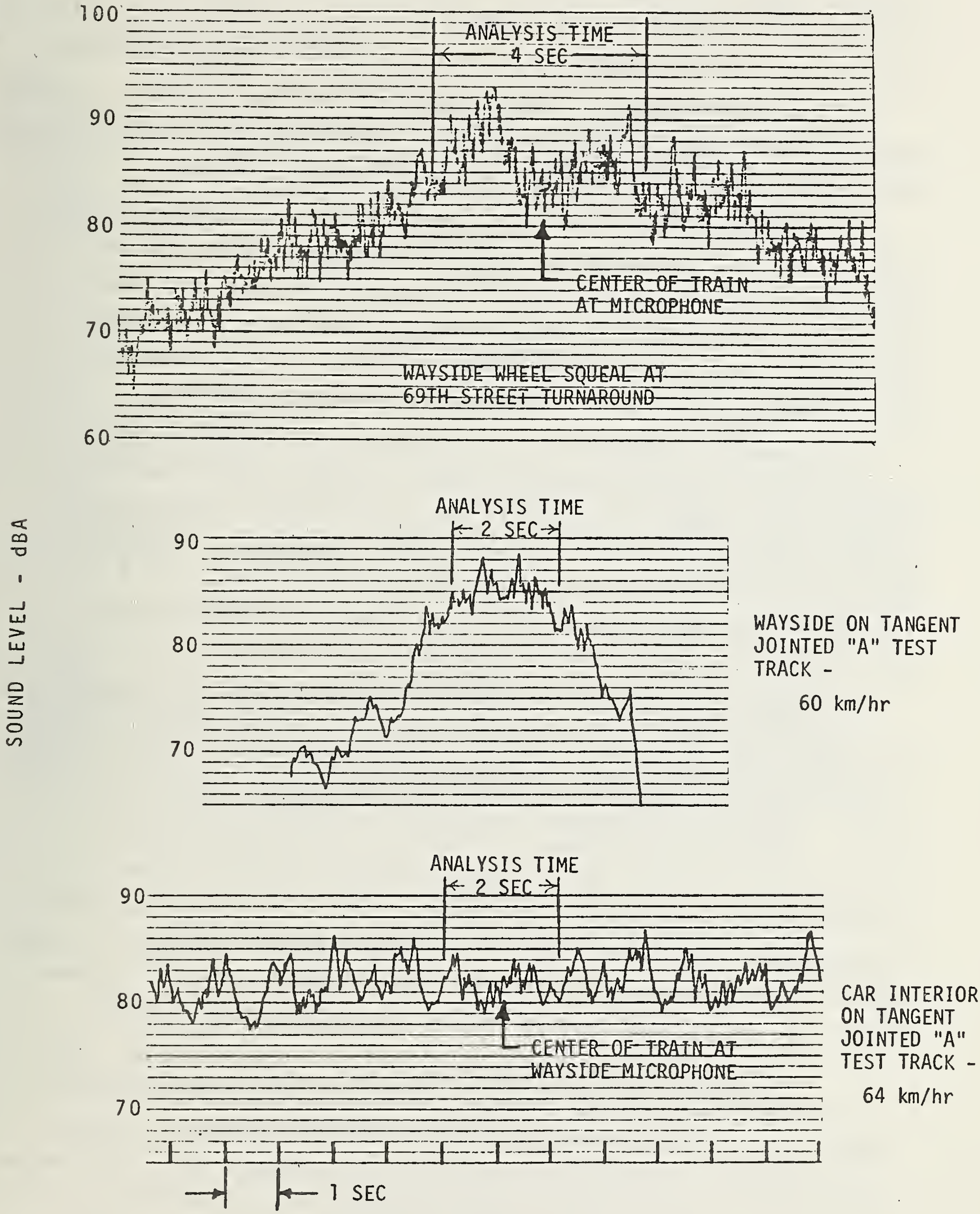


FIGURE 3-3 EXAMPLES OF TIME HISTORIES OF ACOUSTIC SIGNALS WITH INDICATION OF DATA REDUCTION SAMPLE LENGTH

The data sample lengths used for the analysis of the rms level were of 1, 2, or 4 second length, with the 1 second length used only for very short duration events such as high speed, 80km/hr, passbys.

Two microphones were used to measure interior noise: one over the truck and one at the car center. The A-weighted levels given in this report are linear averages for the two microphones.

Although 1/3 octave band levels are being obtained in this study, the analysis is primarily concerned with the A-weighted levels. Due to unexpected trends of some data sets, to clarify the results it was necessary to graphically plot and inspect many of the 1/3 octave spectra. The measurements that have been plotted are included in the appendices.

Appendix A presents the spectra of all data that were taken on the test track section of the TW test track samples. Appendix B presents the spectra for car interior and wayside data on section A of the TJ test track. Appendix C presents the spectra from the tests over the FROG test section. A number of average spectra for wheel squeal on the turnaround test tracks are presented in Appendix D.

Inspection of the 1/3 octave spectra given in Appendices A, B, and C reveals the effect of the notch filter that was used to remove the high level pure tone created by the traction motor fans. The notch filter was tuned to a frequency equal to 13.13 times the train speed in km/hr. At 40 km/hr this is just over 500 Hz and at 80 km/hr just over 1000 Hz. The dip in the spectra created by the notch filter is evident in most of the analyses indicating that it is effectively removing the pure tone while influencing the level only in one or two 1/3 octave bands and not significantly influencing the overall levels.

Referring to the 1/3 octave data, it appears that some of the A-weighted levels inside the trains were influenced by a peak that intermittently occurs at 2000 to 4000 Hz. Since this peak does not show up in any of the wayside data, the noise source must be inside the train, probably a wind whistle at a

door or window seal. The influence of this peak is discussed in subsequent sections.

Analysis and interpretation of the acoustic data in the *tangent* test sections is considerably simplified by defining a noise rating that removes, or at least reduces, the influence of speed on noise level. The noise rating selected for this study is

$$L_A' = L_A - 30 \log_{10} \left[\frac{V}{60 \text{ km/hr}}\right]$$

where L_A and V are the measured A-weighted noise level and speed (in km/hr), respectively, and L_A' is the noise rating. Since the wayside noise level has generally been found to be proportional to K log [V], where K is typically between 24 and 35, L_A' approximately represents the A-weighted noise level normalized to 60 km/hr (37 mph), a typical speed for the SEPTA system trains.

The tests with the various different trains and tracks can be compared directly using the average values of L_A'. Comparison of the various treatments using L_A' could obscure speed effects such as one resilient wheel being more effective at low speed and another being more effective at high speed. However, these comparisons do appear to be a valid indication of the relative effectiveness of the various treatments.

4. RESULTS OF TESTS

The analysis of the acoustic results of the first three test phases is presented in this section. Five test trains were included in the acoustic testing, as follows:

a. Train 1 - Cars 623 and 613, worn standard wheels
b. Train 2 - Cars 755 and 756, new/trued standard wheels
c. Train 3 - Cars 628 and 645, Acousta Flex resilient wheels
d. Train 4 - Cars 626 and 631, Penn Bochum resilient wheels
e. Train 5 - Cars 609 and 630, SAB resilient wheels

For clarity in the following text, references to test results with each set of wheels are referenced to the specific wheel set.

Table 4-1 is a tabulation of the schedule of testing, rail grinding, wheel truing and other actions for reference in review of the following data tables and sections on test results for each type of noise reduction procedure.

Table 4-2 presents a tabulation of the number of runs or passbys for which acoustic data was recorded for each test condition. The overall data tables, Tables 4-3 through 4-11 present the average results in terms of A-weighted sound level normalized to 60 km/hr (37 mph) speed - L_A'. Because there is such a large quantity of individual data points for each test condition, it is necessary to perform a considerable degree of averaging and simplification of the data in order to clearly observe the effects of the noise reduction treatments tested. However, the data tables, Tables 4-3 through 4-11,

are presented to permit the reader to evaluate the basic results or perform different analysis than presented herein.

Sections 4.1 through 4.6 present discussion and analysis of the results - indicating the effects of rail grinding, wheel truing and resilient wheels on reducing noise - as observed by the Phase I, II and III tests.

The Phase III tests did include a set of measurements not presented in the overall data tables. Because of the fact that the Phase I and II results showed an apparent discrepancy in some of the interior noise levels, questions were raised regarding the possibility of ventilation openings or other car body openings being open on some occasions and closed on others. It was found that there are ventilation openings in the car roofs which have thermostatically controlled dampers. Since the status of these openings during the early tests was not known, the Phase III tests included runs for identical conditions with the vents both open and closed. Table 4-12 presents the results of those tests.

The conclusion from the analysis and comparisons of the data is that for most of the earlier tests the vents were open. The exceptions which affected the data were primarily the Phase IB tests and this factor must be taken into account in analyzing the data. The results from the Phase III tests provide a basis for a "normalizing" factor to correct those data points where the vents were closed, i.e., in the "non-normal" status. Also the noise levels observed provide a basis for identifying those runs where the vents were closed and the normalizing factor should be used in interpreting the data. Only the data with the vents open are presented for the Phase III tests in data Tables 4-4, 4-6, 4-8 and 4-9 which indicate car interior noise levels.

Using standard statistical tests, the Students "t" test, it is possible to estimate the statistical significance of the difference in the mean values of L_A'. Based on the pooled standard deviation of 0.9 dBA for the TW and TJ wayside and interior tangent track data, when the difference between two mean values is 1.0 dBA, there is 95 percent confidence that the difference is more than random fluctuation. This assumes that both of the means consist of six examples. Hence, in the analysis of the tangent track data, it can be assumed that differences less than 1 dBA are statistically insignificant; and differences greater than 1.0 dBA are statistically significant. The same statistical tests can be applied to the wheel squeal data in Tables 4-3 and 4-4. The pooled standard deviation for the wheel squeal data is 2.6 dB. With six test examples of each condition, this indicates that a difference of 3.0 dBA is necessary for 95 percent confidence that two mean values are really different.

The average levels of L_A' for the tests are tabulated in Tables 4-3 through 4-12. The standard deviation for each data listing is tabulated in parenthesis. With the normalizing procedure used to obtain L_A', the variation can result from both normal experimental deviations and by the speed dependence of L_A' being different than the 30 log (speed) assumed in the normalizing procedure.

TABLE 4-1. OUTLINE OF TESTING, TRACK MAINTENANCE AND WHEEL TRUING FOR THE PHASE I, II AND III TESTS

Test Phase	Test Date	Description
--	April 12, 1976	Tested worn standard wheel train on-blocks for propulsion equipment noise and on TW test track for overall wayside noise.
IA	July 14-15, 1976	Tested worn standard and new standard wheel trains on the TW, TJ and TURN test tracks.
--	July 26-Aug. 13, 1976	Entire Turnaround and TW test tracks ground with rail grinder. TJ test track Segment B joint bars changed.
IB	Aug. 17-19, 1976	Tested the worn standard and new standard wheels on the TW, TJ, TURN and SUB 1, 2 and 3 test tracks.
--	Aug. 23-27, 1976	Trued new standard wheels
IC	Sept. 1-2, 1976	Tested the worn standard and trued new standard wheels on the TW and TURN test tracks.
--	Sept. 24 , 1976	Completed installation of wheels on all three resilient wheel trains.
IIA	Oct. 2-4, 1976	Tested all 3 resilient wheel trains on all test tracks, the worn-standard on TJ & TW, and trued-new standard on the TW, TJ, and TURN
--	Oct. 12-13, 1976	TJ and SUB 1, 2 and 3 test tracks ground with rail grinders.

TABLE 4-1. (CONT.)

Test Phase	Test Date	Description
IIB	Oct. 14-15, 1976	Tested all five test trains on the TJ, SUB 1, 2 and 3, FROG and ELESTN test tracks.
--		9 months wear period with all trains operating in revenue service. Failures of some resilient wheels occurred during this period.
III	July 14, 1977	Tested worn standard, new standard and remaining resilient wheel trains for interior noise on the TURN, TW, TJ, SUB 1 and SUB 2 test tracks and for wayside noise on the TW and TURN test tracks. Also tested the worn standard wheel train and a resilient wheel train with ventilation dampers both open and closed on the TURN, TW, TJ, SUB 1 and SUB 2 test tracks.

TABLE 4-2. LISTING OF NUMBER OF TEST RUNS FOR EACH TEST CONDITION

Test Phase and Track	Train				
	Worn Standard	New Standard	Acousta Flex	Penn Bochum	SAB
Phase IA					
Welded-TW	7	8			
Jointed-TJ	7	8			
Curve-TURN	9	6			
Phase IB					
Welded-TW	9	9			
Jointed-TJ	9	9			
Curve-TURN	6	6			
Welded-SUB 1	7	7			
Jointed-SUB 2	7	7			
Station-SUB 3	4	4			
Phase IC					
Welded-TW	8*	8			
Curve-TURN	6	6			
Phase IIA					
Welded-TW	2	6	6	6	6
Jointed-TJ	2	6	6	6	6
Curve-TURN		4**	6	6	6
Welded-SUB 1			6	14	7
Jointed-SUB 2			6	8	7
Station-SUB 3			4	4	4

* The worn standard wheel train was tested as a single car in this series.

** The track was wet for these 4 runs and the data has, therefore, been deleted.

TABLE 4-2. (CONT.)

Test Phase and Track	Train				
	Worn Standard	New Standard	Acousta Flex	Penn Bochum	SAB
Phase IIB					
Jointed-TJ	6	6	6	6	6
Station-ELESTN	4	4	4	4	5
Frog-FROG	6	6	6	6	8
Welded-SUB 1	6	6	6	6	6
Jointed-SUB 2	6	6	6	6	6
Station-SUB 3	4	4	4	4	4
Phase III					
Welded-TW	5	3	*(6)	*(6)	3
Jointed-TJ	5	3	(6)	(6)	3
Curve-TURN	5	3	(6)	(6)	3
Welded-SUB 1	5		(6)	(6)	
Jointed-SUB 2	5		(6)	(6)	

* For the Phase III tests the remaining Acousta Flex wheels car and Bochum wheel car were run as a 2-car train. Thus wayside noise data is for the combined train while interior noise is for the individual wheels. Interior noise data was taken only in the Acousta Flex wheel car because it was the car used for the original data, whereas the remaining Bochum wheel car was not the car used for the Phase I and II interior measurements.

TABLE 4-3. AVERAGE A-WEIGHTED SOUND LEVELS - L_A -dBA
WAYSIDE NOISE - TURN TEST TRACKS

Test Phase	Turn Track	Train				
		Worn Standard	New Standard	Acousta Flex	Bochum	SAB
IA	Control	90.7 *(1.3)	86.1 (1.6)			
	Test	90.7 (1.1)	85.5 (1.6)			
	AVG.	90.7	85.8			
IB Ground Rail	Control	93.2 (1.4)	88.0 (3.2)			
	Test	92.8 (2.2)	88.4 (2.1)			
	AVG.	93.0	88.2			
IC Trued New Wheels	Control	91.8 (3.5)	89.2 (1.6)			
	Test	90.8 (2.2)	92.4 (3.3)			
	AVG.	91.3	90.8			
IIA New Resil. Wheels	Control			80.4 (3.6)	79.2 (3.6)	85.3 (2.1)
	Test			77.6 (1.2)	79.2 (1.9)	86.1 (6.3)
	AVG.			79.0	79.2	85.7
III After Wear	Control	90.8	92.0	79.5**	79.5**	81.0
	Test	91.0	89.8	75.8**	75.8**	79.0
	AVG.	90.9	89.9	77.6**	77.6**	80.0

* Numbers in parentheses () are the data standard deviations. Phase III tests have an insufficient number of runs for calculation of standard deviation.

** One Acousta Flex car and one Bochum car run as a 2-car train.

TABLE 4-4. AVERAGE A-WEIGHTED SOUND LEVELS - L_A -dBA
CAR INTERIOR NOISE - TURN TEST TRACKS

Test Phase	Turn Track	Train				
		Worn Standard	New Standard	Acousta Flex	Bochum	SAB
IA	Control	75.8 *(0.5)	73.5 (1.1)			
	Test	79.6 (0.5)	73.5 (3.0)			
	AVG.	77.7	73.5			
IB Ground Rail	Control	76.3 (0.9)	74.4 (0.6)			
	Test	78.2 (1.2)	76.4 (0.9)			
	AVG.	77.2	75.4			
IC Trued New Wheels	Control	78.1 (4.4)	76.1 (3.3)			
	Test	82.8 (4.3)	80.2 (3.0)			
	AVG.	80.4	78.1			
IIA New Resil. Wheels	Control			75.3 (1.8)	74.4 (3.0)	77.7 (0.9)
	Test			74.8 (1.5)	72.2 (1.7)	79.9 (3.4)
	AVG.			75.1	73.3	78.7
III After Wear	Control	75.9	76.6	73.7		74.4
	Test	77.0	76.9	71.8		73.6
	AVG.	76.4	76.8	72.8		74.0

* Numbers in parentheses () are the data standard deviations. Phase III tests have an insufficient number of runs for calculation of standard deviation.

TABLE 4-5. AVERAGE A-WEIGHTED SOUND LEVELS - L_A'-dBA
WAYSIDE NOISE - TANGENT WELDED TEST TRACKS

Test Phase	TW Track	Train					Average Standard Wheels	Average Resil. Wheels
		Worn Standard	New Standard	Acousta Flex	Bochum	SAB		
IA	Control	81.6 *(1.4)	79.2 (.3)				80.3	
	Test	83.1 (1.0)	82.0 (.7)				82.4	
	AVG.	82.3	80.7				81.4	
IB	Control	83.8 (.8)	80.9 (.2)				82.4	
Ground Rail	Test	83.9 (.7)	81.8 (.9)				82.8	
	AVG.	83.8	81.4				82.6	
IC	Control	**84.7 (.8)	83.8 (1.3)				83.5	
Trued New Wheels	Test	**86.6 (1.4)	84.4 (1.1)				84.8	
	AVG.	85.7	84.1				84.1	
IIA	Control		83.4 (1.2)	83.5 (.8)	83.8 (1.6)	82.3 (1.5)	83.4	83.2
New Resil. Wheels	Test		82.1 (.9)	81.5 (.9)	82.4 (1.2)	81.2 (1.7)	82.1	81.7
	AVG.		82.7	82.4	83.2	81.8	82.7	82.5
III	Control	83.2	84.1	84.2	84.2†	85.7†	83.6	85.0
After Wear	Test	83.6	83.0	84.0	84.0†	84.1†	83.3	83.9
	AVG.	83.4	83.6	84.1	84.1†	84.9†	83.5	84.5

* Numbers in parentheses () are the data standard deviations.

** Single car data adjusted upward 1.5 dB to correspond to 2-car train data.

† One Acousta Flex car and one Bochum car run as a 2-car train.

TABLE 4-6. AVERAGE A-WEIGHTED SOUND LEVELS - L_A'-dBA
CAR INTERIOR NOISE - TANGENT WELDED TEST TRACKS

Test Phase	TW Track	Train					Average Standard Wheels	Average Resil. Wheels
		Worn Standard	New Standard	Acousta Flex	Bochum	SAB		
IA	Control	80.6 *(1.0)	74.6 (.8)				77.1	
	Test	79.6 (.8)	75.4 (.8)				77.2	
	AVG.	80.0	75.0				77.1	
IB Ground Rail	Control	**76.6 (.6)	**73.1 (.8)				74.5	
	Test	**76.9 (.8)	**73.6 (1.0)				75.2	
	AVG.	76.8	73.4				75.1	
IC Trued New Wheels	Control	79.8 (.9)	77.2 (.6)				78.6	
	Test	79.7 (.9)	77.0 (.4)				78.4	
	AVG.	79.7	77.1				78.5	
IIA New Resil. Wheels	Control		77.4 (1.0)	76.5 (.8)	76.2 (1.4)	75.5 (.6)	77.4	76.1
	Test		77.6 (1.6)	76.7 (.8)	76.5 (.6)	75.8 (.8)	77.6	76.3
	AVG.		77.5	76.6	76.3	75.6	77.5	76.2
III After Wear	Control	77.9	**78.5	76.8		**78.2	77.9	76.8
	Test	78.4	** 78.8	76.9		**77.9	78.4	76.9
	AVG.	78.2	78.6	76.8		78.0	78.2	76.8

* Numbers in parentheses () are the data standard deviations.

** Data taken with vent dampers closed.

TABLE 4-7. AVERAGE A-WEIGHTED SOUND LEVELS - L_A'-dBA WAYSIDE NOISE - TANGENT JOINTED TEST TRACKS

Test Phase	TJ Track	Train					Average Standard Wheels	Average Resil. Wheels
		Worn Standard	New Standard	Acousta Flex	Bochum	SAB		
IA	B	89.7 *(.7)	88.7 (.9)				89.2	
	A	88.9 (.5)	87.3 (.7)				88.1	
	Control	89.7 (.7)	88.6 (1.0)				89.1	
	AVG.	89.4	88.2				88.8	
IB Align Track B	B	89.3 (.6)	86.4 (.6)				87.9	
	A	89.6 (.8)	87.9 (.8)				88.7	
	Control	90.5 (1.1)	88.6 (1.4)				89.6	
	AVG.	89.8	87.6				88.7	
IIA Trued New Stand. Wheels	B		88.3 (1.8)	85.4 (.3)	86.7 (.3)	87.6 (1.2)	88.3	86.6
	A		88.8 (1.1)	87.6 (.3)	88.4 (1.0)	89.0 (1.3)	88.8	88.3
	Control		88.6 (1.8)	87.4 (.6)	87.8 (1.1)	88.5 (1.1)	88.6	87.9
	AVG.		88.6	86.8	87.6	88.4	88.6	87.6
IIB Ground Tracks A & B	B	87.8 (.6)	85.6 (.6)	83.6 (.9)	82.7 (.2)	84.4 (.5)	86.7	83.6
	A	88.2 (.7)	85.6 (1.0)	84.5 (.5)	84.4 (.6)	85.2 (.5)	86.9	84.7
	Control	89.4 (1.3)	88.6 (1.5)	87.1 (1.0)	86.7 (1.0)	88.4 (1.0)	89.0	87.5
	AVG.	88.5	86.6	85.1	84.6	86.1	-	-
III After Wear	---							

* Numbers in parentheses () are the data standard deviations

TABLE 4-8. AVERAGE A-WEIGHTED SOUND LEVELS - L_A'-dBA
CAR INTERIOR NOISE - TANGENT JOINTED TEST TRACKS

Test Phase	TJ Track	Train					Average Standard Wheels	Average Resil. Wheels
		Worn Standard	New Standard	Acousta Flex	Bochum	SAB		
IA	B	83.1 (.3)	78.7 (.9)				80.7	
	A	82.4 (.5)	78.5 (.5)				80.3	
	Control	83.5 (.5)	78.5 (1.5)				81.2	
	AVG.	83.0	78.8				80.8	
IB Align Track B	B	80.6 (.5)	77.6 (.5)				79.1	
	A	80.5 (.5)	77.4 (.5)				79.0	
	Control	81.8 (.4)	79.1 (.9)				80.4	
	AVG.	81.0	78.0				79.5	
IIA Trued New Stand. Wheels	B		80.3 (.4)	80.8 (1.0)	79.5 (.9)	80.2 (1.0)	80.3	80.4
	A		80.0 (.8)	79.8 (.3)	79.9 (.4)	80.2 (.5)	80.0	80.0
	Control		81.4 (1.0)	81.2 (.6)	80.6 (1.0)	81.2 (.6)	81.4	81.0
	AVG.		80.5	80.6	80.0	80.7	80.2	80.5
IIB Ground Tracks A & B	B	80.5 (.7)	80.6 (.4)	77.8 (.8)	78.7 (.7)	79.2 (.5)	80.5	78.6
	A	80.5 (.5)	79.6 (.4)	79.5 (.8)	79.4 (.8)	79.2 (.4)	80.0	79.3
	Control	82.2 (.7)	81.4 (.5)	81.7 (.8)	81.3 (.5)	81.7 (.4)	81.7	81.6
	AVG.	81.1	80.4	79.7	79.8	80.0		
III After Wear	B	80.8	79.6	78.9		79.6	80.2	79.2
	A	80.0	79.1	78.5		79.1	79.6	78.8
	Control	82.0	80.9	80.7		80.8	81.5	81.1
	AVG.	80.9	79.9	79.4		79.8	-	-

TABLE 4-9. AVERAGE A-WEIGHTED SOUND LEVELS - L_A'-dBA
CAR INTERIOR NOISE - SUBWAY TEST TRACKS

Test Phase	Subway Track	Train					Average Standard Wheels	Average Resil. Wheels
		Worn Standard	New Standard	Acousta Flex	Bochum	SAB		
IA	---							
IB	Welded	82.5 *(.8)	80.1 (1.1)				81.3	
	Jointed	84.5 (.3)	82.4 (.6)				83.4	
IIA	Welded			82.6 (.7)	82.1 (1.0)	80.9 (1.5)		81.9
	Jointed			84.1 (.5)	83.7 (2.4)	84.1 (.7)		84.0
IIB Ground Rail	Welded	85.2 (.8)	81.0 (.6)	79.4 (.5)	79.2 (.9)	80.1 (.8)	83.1	79.6
	Jointed	87.1 (.5)	82.3 (.4)	81.3 (.6)	80.9 (.1)	81.9 (.9)	84.7	81.4
III After Wear	Welded	84.8		83.1			84.8	83.1
	Jointed	87.0		86.1			87.0	86.1

* Numbers in parentheses ( ) are the data standard deviations.

TABLE 4-10 AVERAGE A-WEIGHTED SOUND LEVELS AT THE 15TH STREET SUBWAY STATION - WELDED RAILS

Test Conditions	Train				
	Worn Standard	New Standard	Acousta Flex	Penn Bochum	SAB
Phase IB & IIA Unground Rail					
Skip-Stop	83.9*	84.2	88.1	86.6	87.2
Stop	81.2	78.2	81.8	80.8	82.6
Phase IIB Ground Rail					
Skip-Stop	90.6	85.2	86.0	88.2	83.6
Stop	83.8	82.4	79.2	78.3	80.8

* Slow speeds only, 28 and 35 km/hr. All other skip-stop averaged 40 km/hr.

TABLE 4-11 AVERAGE A-WEIGHTED SOUND LEVELS (L_A) AT THE 63RD STREET ELEVATED STATION - JOINTED RAILS

Test Conditions	Train				
	Worn Standard	New Standard	Acousta Flex	Penn Bochum	SAB
Phase IIB Unground Rail					
Skip-Stop	84.4	82.4	81.8	81.6	81.0
Stop	77.3	75.6	79.0	74.2	76.2

Skip-stop runs averaged 40 mph.

TABLE 4-12. AVERAGE A-WEIGHTED SOUND LEVELS - L_A'-dBA SPECIAL PHASE III TESTS WITH VENTILATOR DAMPERS OPEN AND CLOSED - CAR INTERIOR NOISE

Train

Track	Worn Standard Wheels			Acousta Flex Wheels			Overall Average Difference
	Vents		Average Difference	Vents		Average Difference	
	OPEN	CLOSED		OPEN	CLOSED		
TJ-B	80.8	79.8	1.0	78.9	78.6	.3	
TJ-A	80.0	79.7	.3	78.5	78.4	.1	
TJ-Control	82.0	82.2	-.2	80.7	80.8	-.1	
TW-Control	77.9	77.0	.9	76.8	76.0	.8	
TW-Test	78.4	77.6	.8	76.9	75.3	1.6	
AVG.			0.6			0.5	0.6
SUB 1	84.8	83.3	1.5	83.1	80.3	2.7	
SUB 2	87.0	85.0	2.0	86.1	83.3	2.8	
AVG.			1.7			2.7	2.2
TURN-Test	77.3	76.8	.5	71.7	71.9	-.2	
TURN-Control	75.8	76.0	-.2	74.4	72.9	1.5	
AVG.			0.1			0.6	0.4

4.1 CAR EQUIPMENT NOISE CHARACTERISTICS

Preliminary measurements were performed for the purpose of verifying the appropriateness of the testing procedures and documenting the relative levels of wheel/rail noise and other noise sources on the SEPTA transit cars.

On most transit cars, noise generated by the propulsion equipment such as the traction motors and gear boxes is of the same order of magnitude as wheel/rail noise. There are instances where other noise sources may be important components, but generally wheel/rail noise and propulsion equipment noise dominate.

For one part of the preliminary tests, the SEPTA cars were supported on blocks with the wheels allowed to spin freely. With all of the car equipment operating and the traction motors turning the wheels at a nearly constant rpm, the noise level was measured at locations both inside and adjacent to the car (Figure 4-1). The tests were originally performed on one car of the worn standard wheel test train (Car #613), a car thought to be representative of all of the test cars. Later it was found that the married pair cars have different propulsion equipment from the single cars. Therefore, the cars-on-blocks tests were rerun using the new standard wheel train (Cars #755 and 756), a married pair.

The car-on-blocks tests were performed at the notch 1 and notch 3 settings which resulted in constant wheel spin of 375 and 750 rpm, respectively, on Car #613. On the married pair set, the wheel speed was much less constant. At notch 1 the speed varied from 300 to 540 rpm. At the high speed setting the speed would go through a cycle. A peak speed of 700 to 860 rpm would be reached before an overload relay would open, removing power for 10 to 15 seconds. In this

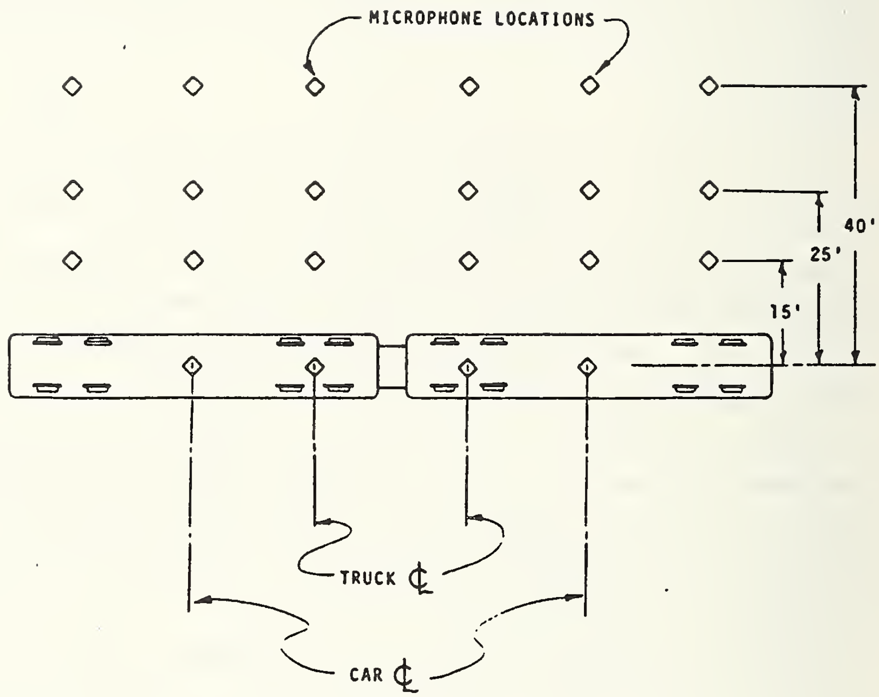


FIGURE 4-1. MEASUREMENT LOCATIONS WITH CARS ON BLOCKS

time the wheels would coast down to about 300 rpm before the relay would reset, repeating the cycle.

In both sets of tests, acoustic measurements were taken at the wayside and in the car interior. Unfortunately, it was impossible to obtain valid data inside Cars #755 and 756 due to excessive shaking of the cars.

The results of the car-on-blocks tests showed that there is an intense tonal noise at the blade passage frequency of the traction motor cooling fans. This tonal noise influences, and often dominates, the A-weighted levels for the propulsion equipment noise. As is typical for fans, the amplitude of the tonal noise increases at approximately the fourth to fifth power of speed. Hence, the fan creates a small peak in the car-on-blocks spectra at low speeds, barely identifiable inside the car, and a very large peak at the high speed - as much as a 12 dB greater level than adjacent 1/3 octave bands. At high speeds, greater than about 60 km/hr, this peak becomes very evident to the ear and is a principal component of the 1/3 octave spectra of wayside passby noise on welded track. The tonal noise was more intense for Car #613 than for Cars #755 and 756.

The tonal or pure tone noise produced by the traction motor fan necessitated an alteration of the data reduction procedure. A tunable notch filter was introduced into the system as shown in Figure 4-2. For each measurement analyzed, the frequency of the notch filter was adjusted to the fan blade passage frequency. This reduced the efficiency of the data analysis, however, the pure tone peak was adequately removed without significantly affecting the remainder of the spectrum. The tunable notch filter was used in the data analysis for all of the tangent track measurements except STATION-STOP tests. The net effect of the use of the filter is to decrease the influence of propulsion equipment noise on the overall noise level.

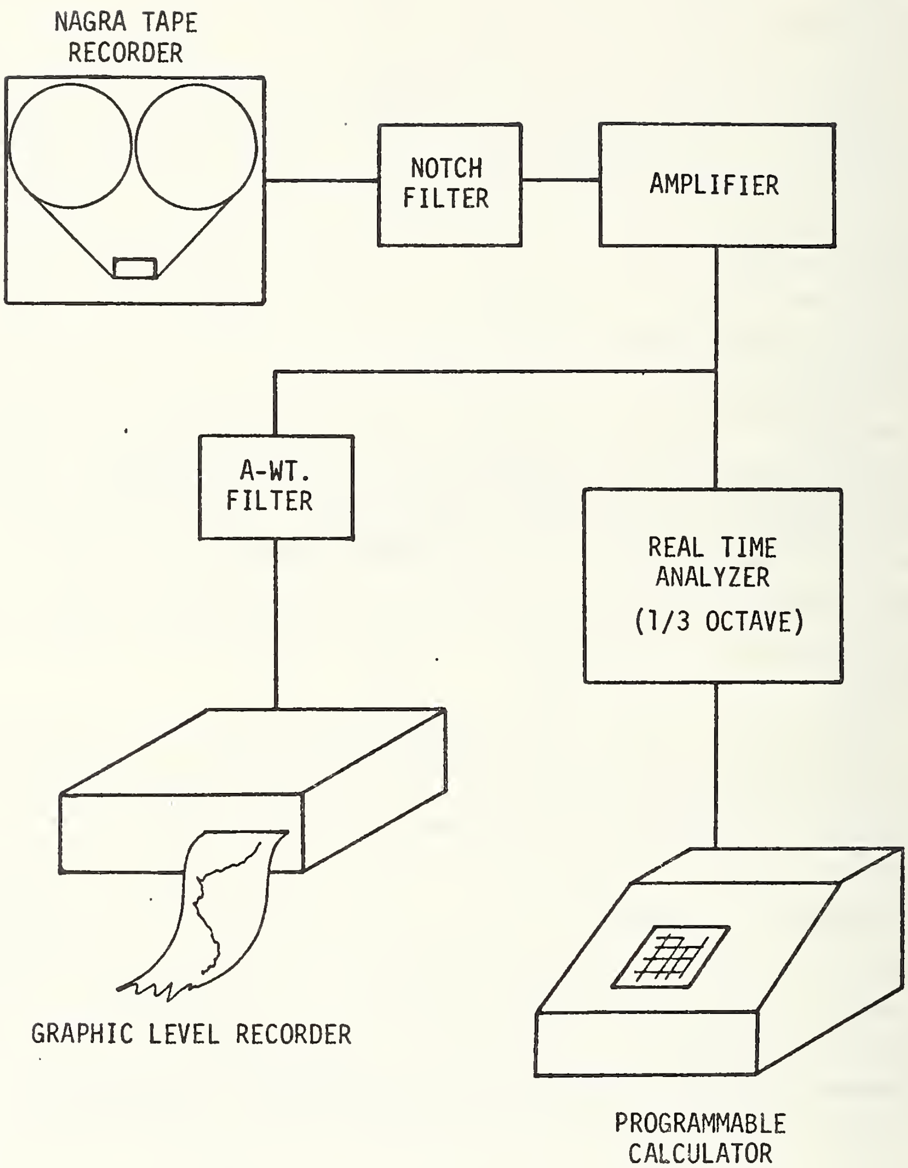


FIGURE 4-2. DATA REDUCTION EQUIPMENT BLOCK DIAGRAM

The effect of the notch filter is illustrated in Figure 4-3a for one example of the car-on-blocks data. Also shown is the frequency response characteristic of the notch filter. In this example the pure tone is at approximately 700 Hz. With the notch filter in the circuit, the spectrum is unchanged except in the 630 and 800 Hz 1/3 octaves where the pure tone clearly dominates the original levels. The 1/3 octave filters in the real time analyzer do not have perfectly vertical skirts. Hence, a high level pure tone in one 1/3 octave may influence the levels in adjacent 1/3 octaves.

Except for the use of the notch filter, the acoustic data collection procedures described in the Test and Evaluation Plan Interim Report were followed closely. Figures 4-3a and 4-3b show the 1/3 octave band spectra of the propulsion equipment noise with and without tonal noise components. Figure 4-3a shows the data for one test point with the single car (#613) and Figure 4-3b shows the averages for all data points from Car #613 and from the married pair, Cars #755 and 756, with one car running.

Using the car-on-blocks data to approximate the spectra for propulsion equipment noise at the test speeds requires speed scaling the results. Speed scaling is required because the car-on-blocks data could be obtained at only two constant speeds - 375 and 750 rpm, equivalent to 50 and 100 km/hr. The data on Figure 4-4 were obtained by approximating the spectra for Car #613 at 50 and 100 km/hr without the influence of the pure tone, interpolating with these spectra to the desired speed, then adding in the pure tone peak in the appropriate 1/3 octave band. Comparing these spectra with the spectra for train passbys also given on Figure 4-4 shows that even if the pure tone peak is removed or disregarded, the broadband propulsion machinery noise is only a small

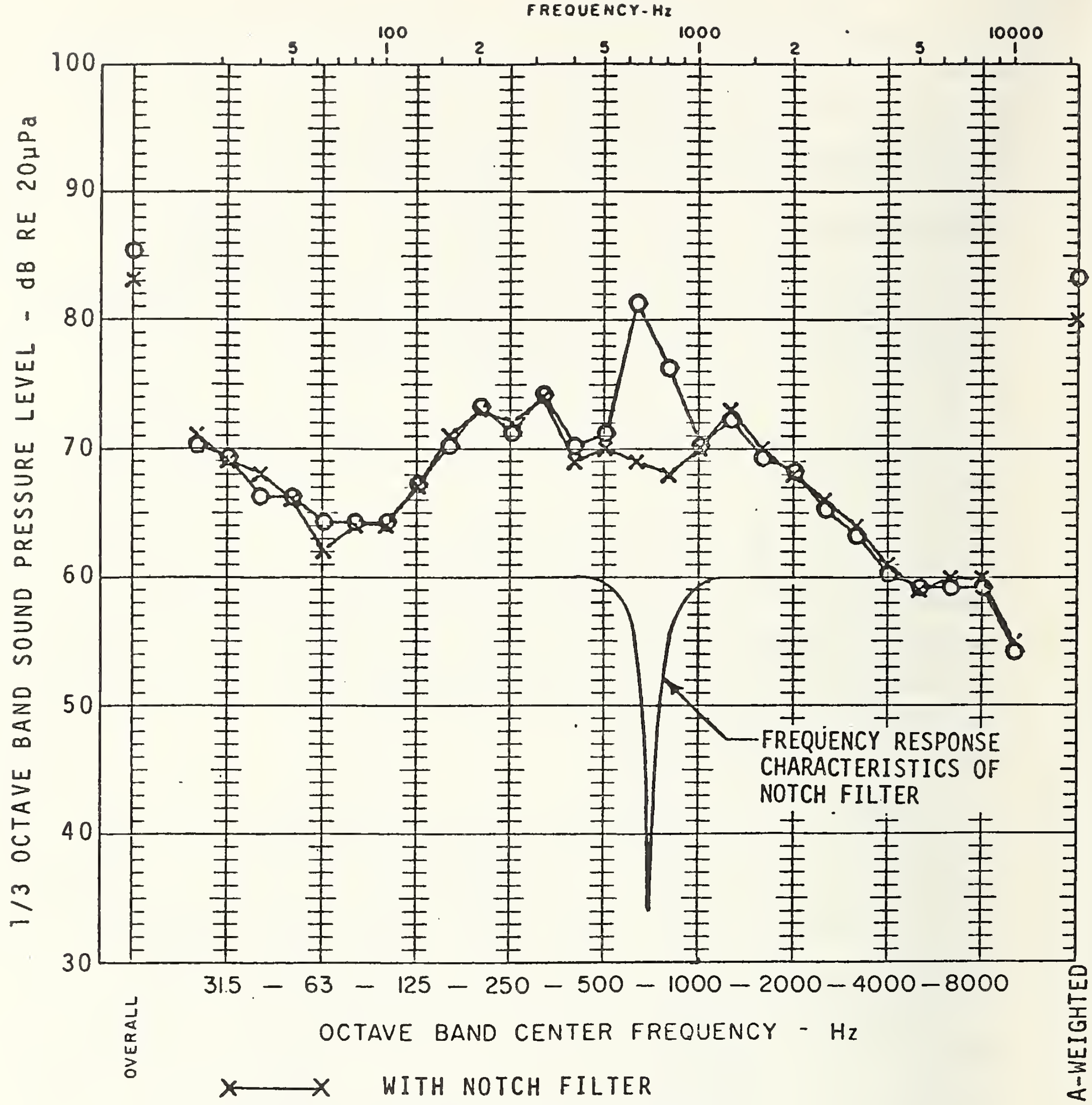


FIGURE 4-3a. CAR-ON-BLOCKS SAMPLE REDUCED WITH AND WITHOUT NOTCH FILTER TUNED TO REMOVE PURE TONE AT FAN BLADE PASS FREQUENCY [658 Hz] - WAYSIDE SAMPLE AT CAR CENTERLINE, 12.5 FT FROM TRACK CENTER

PRELIMINARY SEPTA MEASUREMENTS

APRIL 12, 1976

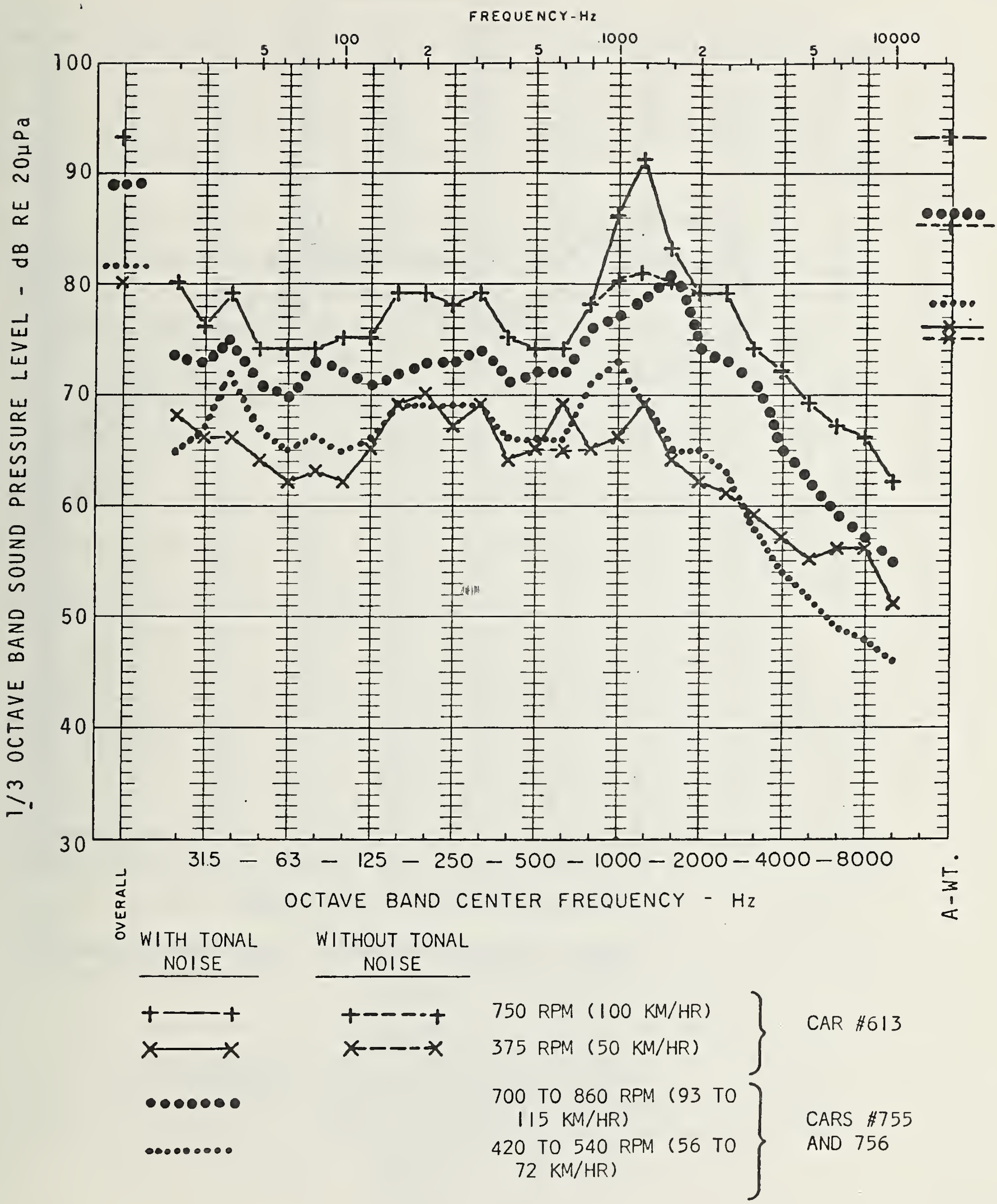


FIGURE 4-3b CAR-ON-BLOCKS WAYSIDE NOISE - AVERAGE OF MEASUREMENTS AT 25 FT POSITIONS. BROKEN LINES INDICATE LEVEL WITH WITHOUT TONAL NOISE AT TRACTION MOTOR FAN BLADE PASSAGE FREQUENCY

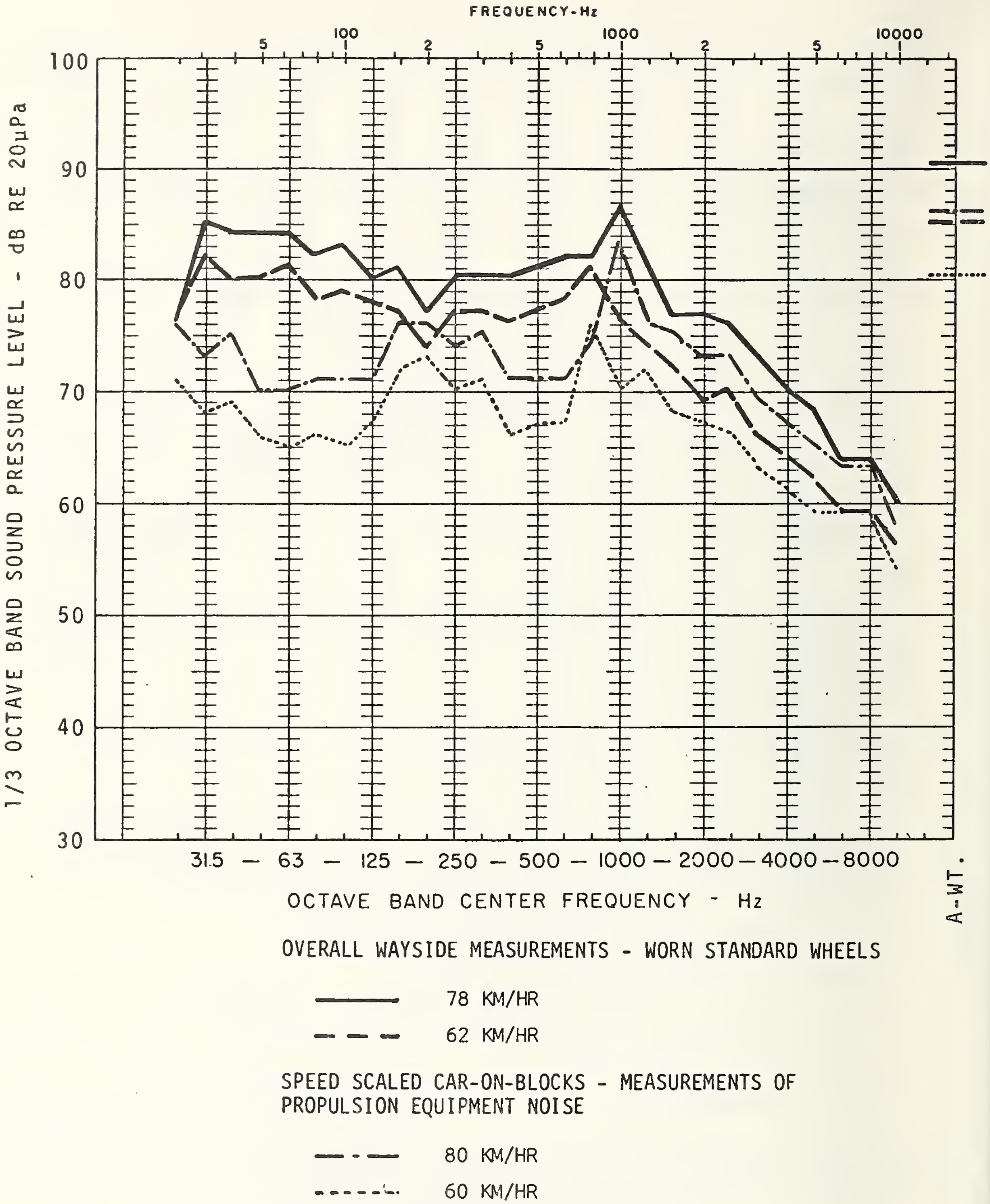


FIGURE 4-4 COMPARISON OF PASSBY NOISE AND CAR PROPULSION EQUIPMENT - 25 FT FROM TRACK CENTERLINE

PASSBY MEASUREMENTS MADE ON TANGENT WELDED BALLAST AND TIE TEST TRACK

amount lower than the overall wayside noise, and hence the wheel/rail noise, over most of the frequency range. Even though the wheel/rail noise is higher, the broadband propulsion machinery noise places a limit on the degree of reduction of wheel/rail noise that can be observed by measuring the overall wayside noise.

Below 125 Hz the propulsion equipment noise is more than 10 dB lower level than the overall wheel/rail noise (including both propulsion equipment and wheel/rail noise). At about 200 Hz the overall noise level decreases while in the same frequency range the propulsion equipment noise increases with the result that the machinery noise is only 1 dB below the overall level in the 200 Hz 1/3 octave band. Between 250 and 1000 Hz the machinery noise ranges from 5 to 10 dB below the overall level. Above 1000 Hz the machinery noise is only 2 to 3 dB below the overall level indicating that wheel/rail noise and propulsion noise are approximately the same level above 1000 Hz.

Figures 4-5a and 4-5b present the overall A-weighted sound level data for the car-on-blocks measurements both as measured and with the influence of the tonal noise removed. To show the comparison with total wayside and interior noise (propulsion equipment and wheel/rail noise) the charts also show the best fit line for the Phase IIA test results on the TW test track for wayside and car interior noise. As discussed above, the data reduction procedures were modified to remove the tonal noise on all of the tests on tangent track, both in the subway and on the ballast and tie tracks elevated structure.

The measurements show that the propulsion machinery noise is higher on the single car (Car #613) than for the married pair cars (Cars #755 and 756) operated separately. With the pure tone component removed, the total wayside noise levels

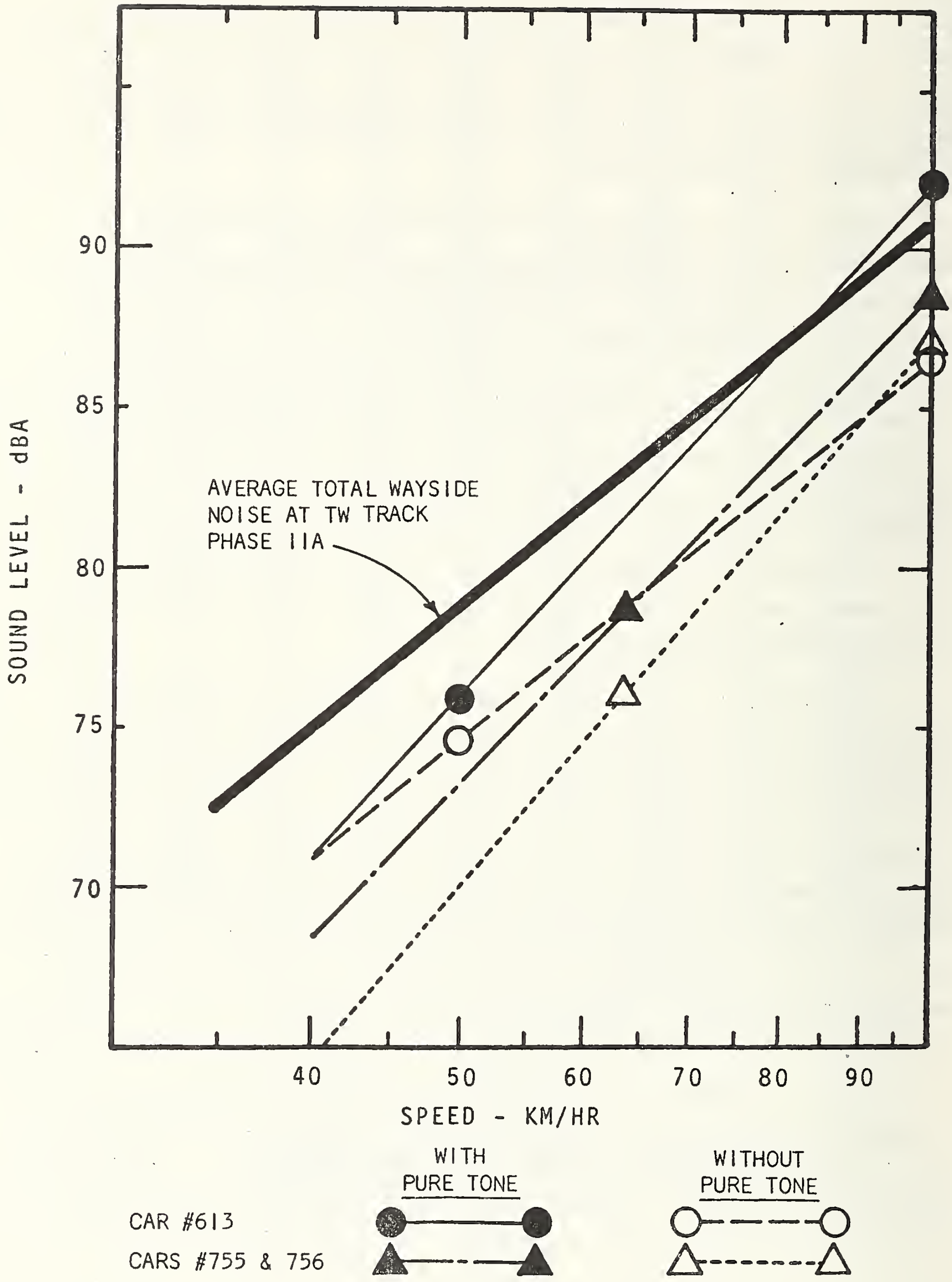


FIGURE 4-5a PROPULSION EQUIPMENT NOISE LEVELS - WAYSIDE - 25 FT FROM TRACK CENTERLINE

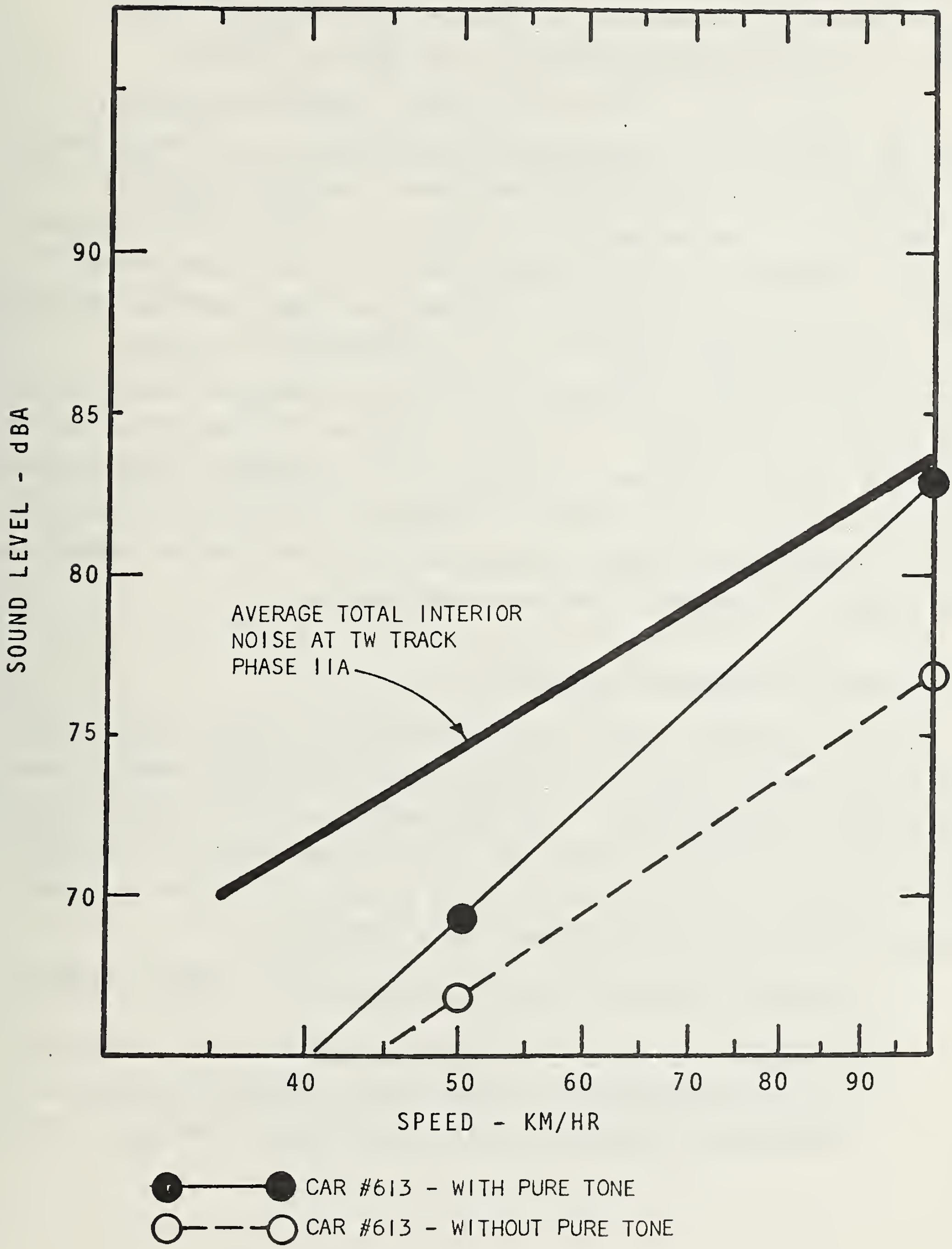


FIGURE 4-5b PROPULSION EQUIPMENT NOISE LEVELS - CAR INTERIOR

for Car #613 are only 4 to 5 dBA above the propulsion equipment noise as measured by the car-on-blocks tests. For the interior measurements, with the tonal noise removed, the noise levels with the car-on-blocks are 6 to 8 dBA lower than the average test results on the TW test track.

The conclusion that can be drawn from these data is that the reduction of wheel/rail noise that can be measured is limited by the propulsion equipment noise. Given the variability of the measurement results for the car-on-blocks results, due both to the inconsistency of the wheel speed and to the normal noise level variations found between similar tests at different times, it is not possible to *exactly* quantify the amount of wheel/rail noise reduction that can be observed in this study. It is, of course, not possible to subtract out the influence of propulsion equipment noise from the total noise. The charts on Figures 4-5a and 4-5b do provide an indication of the limits on wheel/rail noise reduction which can be observed with the SEPTA cars.

4.2 RESULTS FROM RAIL GRINDING

As is apparent from the tabulations of test conditions and tests data, the rail grinding tests included several combinations of parameters. The following list is a summary of the combinations which were included in the tests to develop information on the effects of rail grinding for the various types of rail and the various types of wheels.

1) Tangent Welded, TW, track before and after grinding.

2) Tangent Jointed, TJ, track before changing, after changing joint bars only, after grinding only and after both changing joint bars and grinding.

3) Short Radius Turn, TURN, track before and after grinding.

4) Subway Tangent Welded, SUB 1, track before and after grinding.

5) Subway Tangent Jointed, SUB 2, track before and after grinding.

6) Subway Station, SUB 3, before and after grinding (welded rails).

For each of the rail grinding test conditions given above there were, of course, tests with each of the six types of wheels, except that the new standard wheels before truing were not tested on the TJ and SUB test tracks after grinding. Also, beyond the before/after tests the Phase III tests provided data after nine months wear period for most of the wheel sets and rail configurations.

For all of the before/after rail grinding measurements, wayside and car interior data were taken simultaneously. As discussed in Section 4-1, the data analysis methodology for all tests except the TURN and STATION-STOP tests included the use of a notch filter in order to eliminate the pure tone noise created by the traction motor fans at the blade passage frequency. The filter eliminated the effect of the pure tone on the overall A-weighted sound level without affecting the levels over most of the frequency range.

Several different methods have been used to investigate the acoustic data. The analysis has primarily focused on the L_A' results, however, the speed dependence of the A-weighted levels and the 1/3 octave levels have been inspected for the purpose of understanding the results and in developing conclusions from the overall L_A' results. Appendices A, B and D

present 1/3 octave band analysis plots for a number of the individual data points. These graphs provide considerable information on the details of the wayside and car interior noise from the measurements on the tangent welded, the tangent jointed and the TURN test tracks. Note that for the wayside noise measurements, the frequency of the notch filter is evident on the charts as a dip in the spectra in the frequency range between 500 and 1000 Hz.

The inclusion of control sections of track, adjacent to most of the test sections where rail grinding was tested, provided a basis for evaluating any changes in the noise levels due to uncontrolled variables. Further, since measurements were performed on the test and control track segments before rail grinding the inclusion of control tracks provides a basis for deriving normalization factors that separate out the effects of uncontrolled factors and isolate the effects of rail grinding.

The use of a normalization factor was found necessary only in evaluation of the TW wayside data. This was because in the initial test with identical test conditions, it was found that there were significant differences in the wayside noise for the test and control sections. The initial tests were performed before any rail grinding took place. The result of this difference is that a direct comparison of absolute noise levels, considering only the comparison of test and control segment data after grinding the test segment could not be used for determining the effects of rail grinding.

Table 4-13 shows the manner in which the data from the TW track was normalized. The first column is the absolute difference between the average levels on the test track segment and the control track segment. For the Phase IA

tests, when the track segments were in apparently equivalent condition, the noise levels on the test track segment were significantly higher than the levels on the control section; 1.5 dBA higher with the worn standard wheels and 2.8 dBA higher with the new standard wheels. This result indicates that direct comparison of the absolute levels on the control and test segments after rail grinding of the test segment will underestimate the effectiveness of the rail grinding. For this reason the Phase IA results were used to analyze the difference between the TW test and control tracks for subsequent test phases. The normalized results are shown in the second column of Table 4-13 after application of a normalizing factor of 2.2 dBA, the average difference between the results on the control and test track segments for the original series of tests.

Tables 4-14, 4-15 and 4-16 present the final overall results for the rail grinding tests, showing the effects of rail grinding in reducing the overall wayside and car interior noise levels for the various types of wheels on the various types of track. As is apparent from inspection of the figures in Table 4-14 for the tangent welded test track, the grinding did produce significant noise reduction for the wayside noise but did not significantly change the car interior noise. The data for the subway test track indicates essentially no change in the car inteior noise with the worn wheels, some reduction with the new/trued wheels and a significant measurable reduction with the resilient wheels.

Table 4-16 for the tangent jointed test track shows measurable reduction for both the aligning and grinding of the rail with the most significant result being the reduction of wayside noise after both alignment and grinding with the use of the resilient wheels. Unlike the tangent welded test track sections the car interior noise on the jointed rail shows some

TABLE 4-13. AVERAGE DIFFERENCES IN L_A' IN dBA FOR TEST TRACK SEGMENT RELATIVE TO THE CONTROL TRACK SEGMENT - TW TRACK

Test Phase	Wheel Type	Wayside Noise	Normalized Wayside Noise*	Car Interior Noise**
IA	Worn Standard	1.5	-0.7	-1.0
	New Standard	2.8	0.6	0.8
IB	Worn Standard	0.1	-2.1	0.3
	New Standard	0.9	-1.3	0.5
IC	Worn Standrd	1.9	-0.3	-0.1
	Trued Standard	0.6	-1.6	-0.2
IIA	Trued Standard	-1.3	-3.5	0.2
	Acousta Flex	-2.0	-4.2	0.2
	Bochum	-1.4	-3.6	0.3
	SAB	-1.1	-3.3	0.3
III	Worn Standard	0.4	-1.8	0.6
	Trued Standard	-1.1	-3.3	0.3
	Acousta Flex	-0.2	-2.4	-0.3
	SAB	-1.6	-3.8	-0.3

* Normalized per discussion in text.

** Normalized to vents open condition.

TABLE 4-14. RELATIVE NOISE LEVELS AFTER RAIL GRINDING FOR THE TW TEST TRACK

Wheel Type	Wayside Noise		Car Interior Noise	
	Before Wear	After Wear *	Before Wear	After Wear*
Worn Standard	-1.2 dBA	-1.8 dBA	+0.1 dBA	+0.6 dBA
New Standard	-1.3	--	+0.5	--
Trued Standard	-2.6	-3.3	+0.0	+0.3
Acousta Flex	-4.2	-2.4	+0.2	-0.3
Bochum	-3.6	--	+0.3	--
SAB	-3.3	-3.8	+0.3	-0.3

*Nine month wear period.

TABLE 4-15. RELATIVE NOISE LEVELS AFTER RAIL GRINDING FOR THE SUBWAY TEST TRACKS - CAR INTERIOR NOISE

Wheel Type	Welded Rail		Jointed Rail	
	Before Wear	After Wear*	Before Wear	After Wear*
Worn Standard	+0.5 dBA	+0.5 dBA	+0.4 dBA	+0.5 dBA
New/Trued Standard	-1.3	--	-2.3	--
Acousta Flex	-3.2	+0.4	-2.8	-2.0
Bochum	-2.9	--	-2.8	--
SAB	-0.8	--	-2.2	--

*Nine month wear period.

TABLE 4-16. RELATIVE NOISE LEVELS AFTER JOINT ALIGNMENT AND RAIL GRINDING FOR THE TJ TEST TRACKS

Wheel Type	Car Interior Noise - dBA				
	Before Wear			After Wear*	
	Aligned Rail	Ground Rail	Aligned & Ground Rail	Ground Rail	Aligned & Ground Rail
Worn Standard	-1.9	-2.0	-2.0	-2.6	-2.2
New Standard	-0.9	-	-	-	-
Trued Standard	-0.5	-0.3	-0.3	-1.7	-1.2
Acousta Flex	+0.3	-1.0	-2.7	-2.0	-1.6
Bochum	-1.0	-1.1	-1.8	-	-
SAB	-0.5	-1.5	-1.5	-1.6	-1.1

Wheel Type	Wayside Noise - dBA		
	Before Wear		
	Aligned Rail	Ground Rail	Aligned & Ground Rail
Worn Standard	-0.3	-1.4	-1.8
New Standard	-1.9	-	-
Trued Standard	-0.4	-2.2	-2.2
Acousta Flex	-2.1	-3.0	-3.9
Bochum	-1.1	-3.4	-5.1
SAB	-1.1	-2.6	-3.4

*Nine month wear period.

measurable reduction effects due to the aligning and grinding of the jointed rails.

The overall result tables include the data from the Phase III tests after the nine months of wear, and show similar results after the wear period for the tangent welded test track and the tangent jointed test track. However, the subway test track does indicate, in at least one instance, a loss of the noise reduction after the wear.

At the TURN test track, for the initial series of tests, Phase IA, clockwise and counterclockwise direction runs were made. Since there appeared to be differences between the results in the two directions, subsequent to Phase IA, only the runs in the counterclockwise direction were analyzed to minimize the number of uncontrolled variables. Tables 4-3 and 4-4 indicate the average A-weighted sound levels for the various combinations of wheels and track which were tested before and after rail grinding.

Past studies have illustrated the randomness of wheel squeal. Typically the occurrence of wheel squeal on short radius curves is intermittent, with different modes being excited at different times. It is not generally possible to identify reasons for one mode of wheel vibration to be excited instead of another one. The mechanisms of wheel squeal (self-excited slip-stick phenomenon) can be changed by relatively minor changes in track geometry, lubrication, etc. As such the ideal study of wheel squeal would include a large number of tests on several different curves. Unfortunately, only one curve on the SEPTA Market-Frankford Line is suitable for wheel squeal measurements. However, sufficient testing is being performed on this curve to identify the effectiveness of the various methods of controlling wheel squeal.

The wheel squeal produced by standard steel wheels is a very intense squeal with the dominant component being at about 8000 Hz and more intermittent components being 1000 and 2000 Hz. This is somewhat unusual, since the dominant components of wheel squeal are typically in the range of 1000 to 4000 Hz for most transit systems.

The squeal on the turnaround is relatively constant, occurring virtually continuously when a train is moving on the turnaround. To control the squeal, SEPTA greases the inside rail at regular intervals. For consistency it was requested that the greasing be discontinued for at least two weeks prior to each test phase. Of course, variations in the amount of residual grease on the rail could influence the wheel squeal observed in the tests.

Table 4-17 presents the comparative results for noise levels after grinding the TURN tracks compared to before grinding. With the new standard wheel train, the levels at the wayside and the car interior increased after the rails were ground and increased further after the wheels were trued. The average levels on the control and test segments show significant variations - as high as 4 dBA.

The data with the worn standard wheel train show some unexpected variations also. Of particular interest is the variation between Phases IB and IC. The tests were taken approximately two weeks apart with all of the controlled variables (wheel wear, track wear, etc.) nominally identical. However, the variations are quite dramatic with the car interior levels increased an average of 3 dBA.

Another interesting phenomenon within the worn wheel train data is that at the wayside the average level on the control segment is always slightly higher than on the test segment; an average of less than 1 dBA higher. In contrast, the average interior level on the control segment is always lower than on the test segment; an average of 3.5 dBA lower.

With the resilient wheels the character of the squeal sound is dramatically changed, but there is no data for before and after rail grinding because both the test and control track segments were ground before the resilient wheels were run on the TURN track.

The main conclusions that can be drawn from this series of before/after rail grinding tests on the curve test section are:

1. The standard wheels emit a high pitched (6000 to 8000 Hz) squeal noise that is virtually continuous when the train is on the turnaround curve.
2. New standard wheels emit lower noise levels than worn standard wheels.
3. Grinding the rail does not appear to have any positive effect on the noise levels with standard wheels and marginally increases the noise levels on curves.

At the subway station test track two varieties of data were taken, station platform noise levels with skip stops, i.e., with the trains moving through the station at constant speed, and station platform noise levels with the trains stopping at the platform. For the skip stop measurements the data obtained was for the maximum sound level during the

passby, as for the other measurements of this program. For the station stop measurements the sound levels taken were the average of the minimum level as the train approached (before stopping) and the maximum level as the train departed (after stopping)

TABLE 4-17. RELATIVE NOISE LEVELS AFTER RAIL GRINDING COMPARED WITH BEFORE GRINDING FOR THE TURN TEST TRACK*

Wheel Type	Relative Noise Level - dBA			
	Before Wear		After Wear	
	Wayside Noise	Car Interior Noise	Wayside Noise	Car Interior Noise
Worn Standard	+1.4	+1.1	+0.7	-1.3
New Standard	+2.4	+1.9	+4.1	+3.3

*Values are averaged for test and control tracks as both segments were inadvertently ground.

Table 4-18 presents the comparative results for noise levels after grinding the SUB 3 subway station test track. It should be noted that the rails in the 15th Street subway station used for these tests are welded rails, therefore, these results should be considered in comparison with other continuous welded rail results. As is apparent from the data given in Table 4-18 the results for the station measurements were somewhat inconsistent. Part of this inconsistency was due to the fact that the speeds were not well controlled, particularly with the worn standard wheel trains and, in the case of the stop operation data, the operating conditions could not be maintained identical for each stop operation.

In general terms, the data show that with the standard wheels the station platform noise levels were higher after grinding the rail, whereas, with the resilient wheels in most cases the station platform levels were lower by about 2 dB after grinding of the rails.

TABLE 4-18. RELATIVE NOISE LEVELS AFTER RAIL GRINDING FOR THE SUBWAY STATION, SUB 3, TEST TRACK

Wheel Type	Relative Platform Noise Levels - dBA	
	Skip-Stop	Stop
Worn Standard	+3.5*	+2.6
New/Trued Standard	+1.0	+4.2
Acousta Flex	-2.1	-2.6
Bochum	+1.6	-2.5
SAB	-3.6	-1.8

* Levels on unground rails adjusted to 40 km/hr train speed for worn standard only. Others are for average speed of 40 km/hr without adjustment.

4.3 RESULTS FROM WHEEL TRUING

The effects of wheel running surface conditions on wayside and car interior noise have been evaluated by measuring with worn, trued and new (lathe turned) standard steel wheels on the various test tracks. The worn wheels used for this series of tests had been in use in normal revenue service for approximately one year prior to the beginning of testing. The new standard wheels were tested shortly after the wheels were installed on the test train and then they were trued with the SEPTA milling cutter type wheel truing machine and retested.

Table 4-19 presents the average results for comparison of the wayside and car interior noise levels with each of the two varieties of trued wheels - the new lathe turned wheels and the wheels trued using the SEPTA milling cutter truing machine. In each case the table presents the data for comparison of the noise levels with the trued wheels and the worn wheels operating on the same kind of track, i.e., where the trued wheels were operating on ground rail the comparison was made with the worn wheels operating on ground rail, etc. The table includes the results for the measurements at the subway and elevated station platforms as well as the data for the TW, TJ, TURN and subway test tracks.

In general, the data show that in all cases the trued wheels produce less noise, both wayside and car interior, than the worn wheels, with the milling cutter trued wheels showing statistically significantly less noise reduction than the new lathe turned wheels, except for the subway test tracks. It should be noted for the case of the subway test tracks that the new lathe turned wheel tests were done only with the unground rail, whereas with the trued wheels the tests were done only with ground rail. Since the worn wheels showed little difference in level with ground rail compared to unground rail, it is likely that at least part of the additional reduction found with the trued wheels in subway was due to the effect of rail grinding.

Figures 4-6, 4-7, 4-8 and 4-9 present data showing the observed noise levels for the various test conditions on the TW, TJ, TURN and SUB test tracks, respectively. These charts include the data for the worn and trued wheels along with the data for the resilient wheels to provide a graphic representation of the differences in noise levels for the different test conditions and rail configurations. Note that the charts show the

TABLE 4-19. RELATIVE NOISE LEVELS FOR TRUED STANDARD WHEELS COMPARED TO WORN STANDARD WHEELS

Wheel Condition	Relative Noise Levels - dBA					
	TW Track					
	Wayside Noise			Car Interior Noise		
	Unground Rail	Ground Rail	AVG	Unground Rail	Ground Rail	AVG
New-Lathe Turned	-2.1	-2.1	-2.1	-4.6	-3.3	-4.0
Trued	-0.9	-2.2	-1.6	-2.6	-2.7	-2.7
	TURN Track					
	Wayside Noise			Car Interior Noise		
	Unground Rail	Ground Rail	AVG	Unground Rail	Ground Rail	AVG
New-Lathe Turned	-5.0	-4.0	-4.5	-4.2	-3.4	-3.8
Trued	--	-1.4	-1.4	--	-0.6	-0.6
	SUBWAY Test Tracks					
	Car Interior Noise					
	Welded Rail			Jointed Rail		
	Unground Rail	Ground Rail	AVG	Unground Rail	Ground Rail	AVG
New-Lathe Turned	-2.4	--	-2.4	-2.1	--	-2.1
Trued	--	-4.2	-4.2	--	-4.9	-4.9

TABLE 4-19. (CONT'D)

Wheel Condition	Relative Noise Levels - dBA				
	TJ Track - Wayside Noise				
	Unground Rail	Unground & Aligned Rail	Ground Rail	Ground & Aligned Rail	AVG
New-Lathe Turned	-1.3	-2.9	--	--	-2.1
Trued	-0.9	-1.0	-2.6	-2.2	-1.7
	TJ Track - Car Interior Noise				
	Unground Rail	Unground & Aligned Rail	Ground Rail	Ground & Aligned Rail	AVG
New-Lathe Turned	-3.7	-3.0	--	--	-3.4
Trued	-1.1	-0.3	0.0	0.0	-0.4

Wheel Condition	Subway Station Platform Noise Levels - dBA Welded Rail					
	Skip-Stop			Stop		
	Unground Rail	Ground Rail	AVG	Unground Rail	Ground Rail	AVG
New-Lathe Turned	-2.9	--	-2.9	-3.0	--	-3.0
Trued	--	-5.4	-5.4	--	-1.4	-1.4

Wheel Condition	Elevated Station Platform Noise Levels - dBA Unground Jointed Rail	
	Skip-Stop	Stop
Trued	-2.0	-1.7

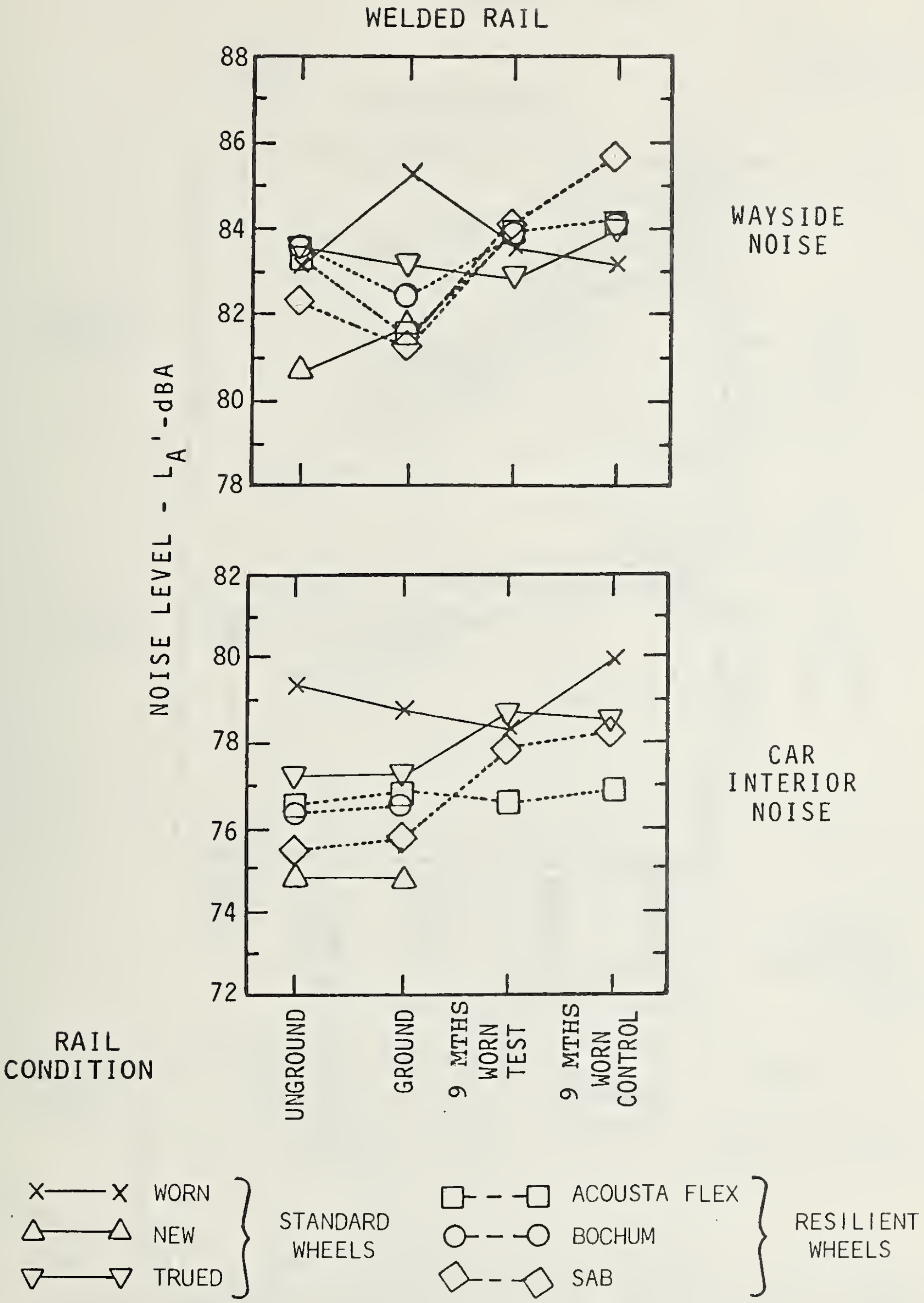


FIGURE 4-6. AVERAGE NOISE LEVELS AT THE TW TEST TRACK FOR VARIOUS WHEELS AND RAIL CONDITIONS

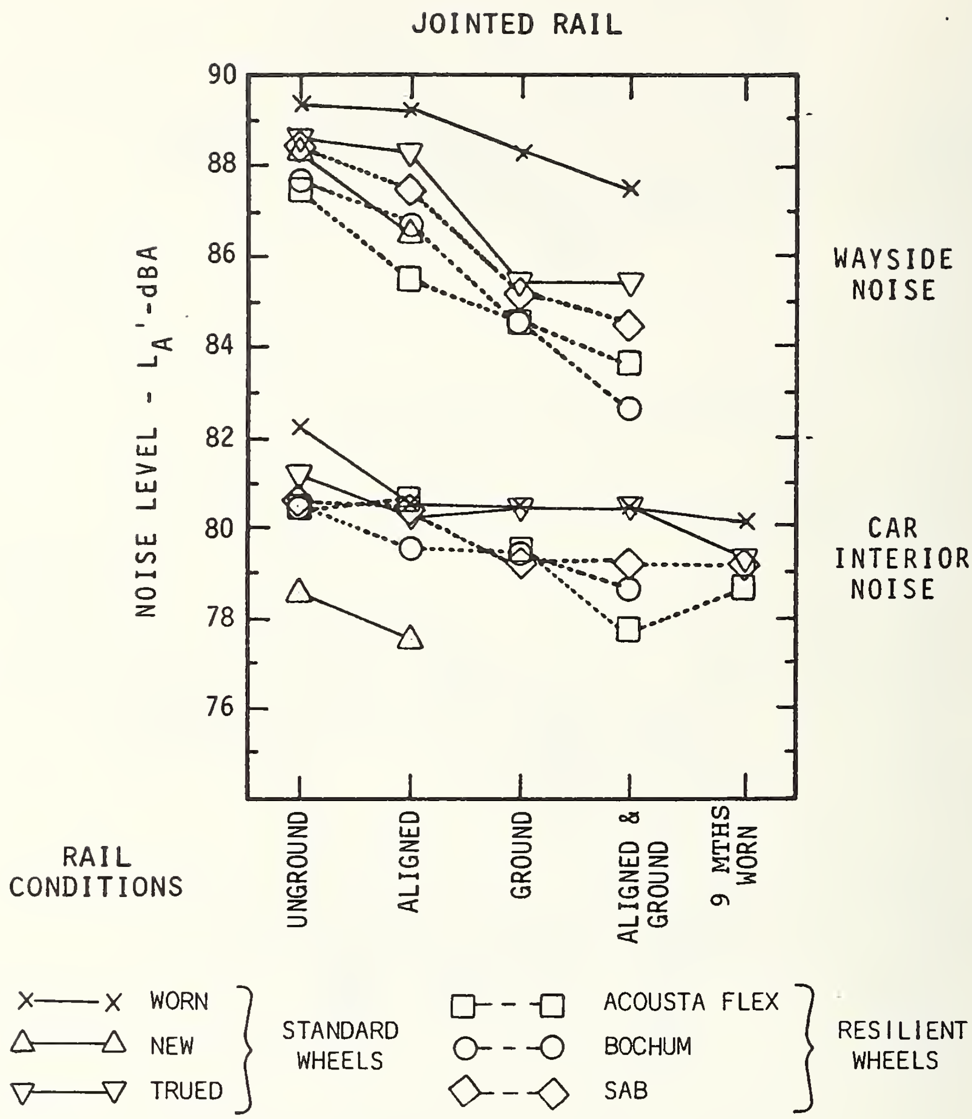


FIGURE 4.7. AVERAGE NOISE LEVELS AT THE TJ TEST TRACK FOR VARIOUS WHEELS AND RAIL CONDITIONS

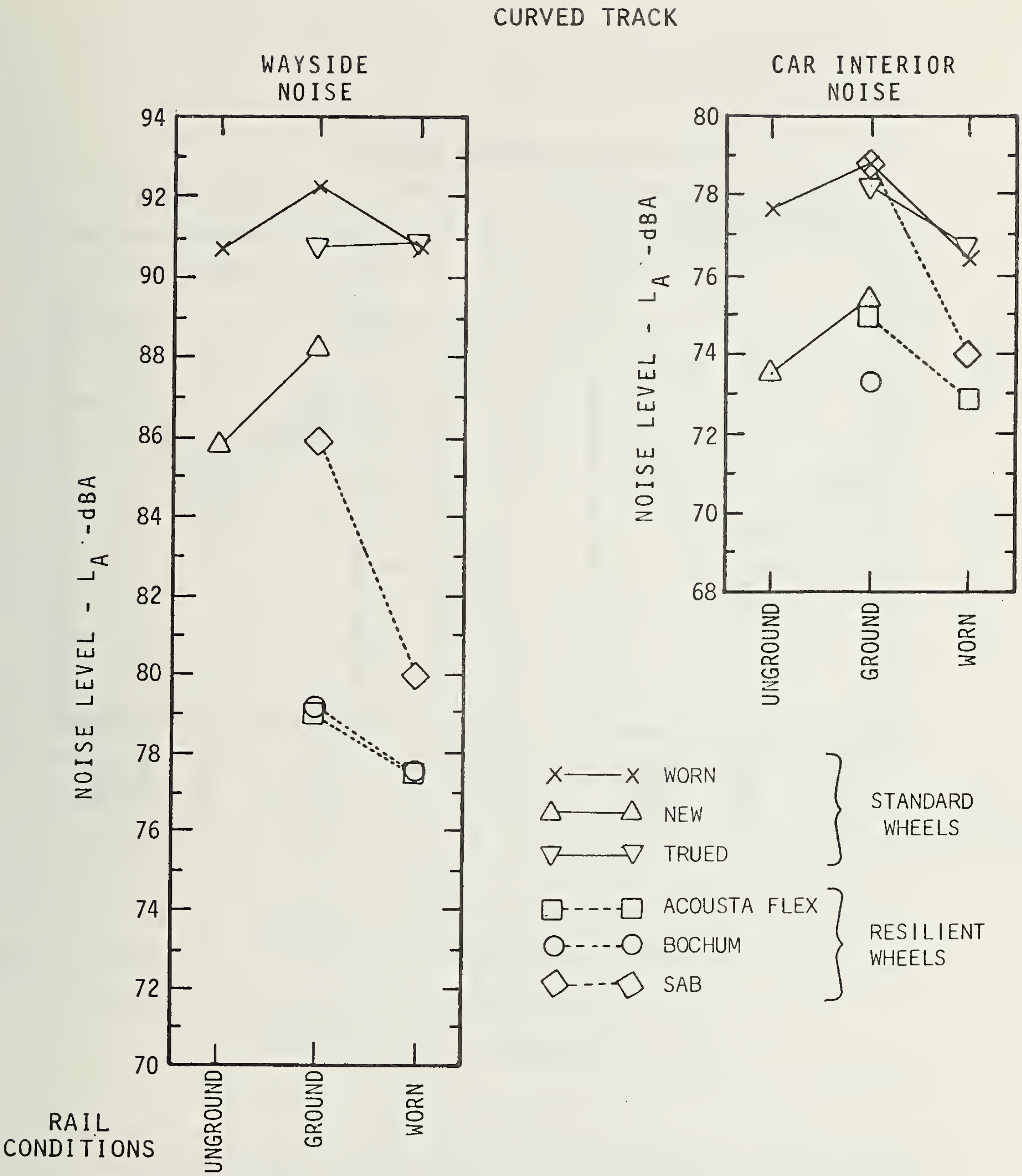


FIGURE 4-8. AVERAGE NOISE LEVELS AT THE TURN TEST TRACK FOR VARIOUS WHEELS AND RAIL CONDITIONS

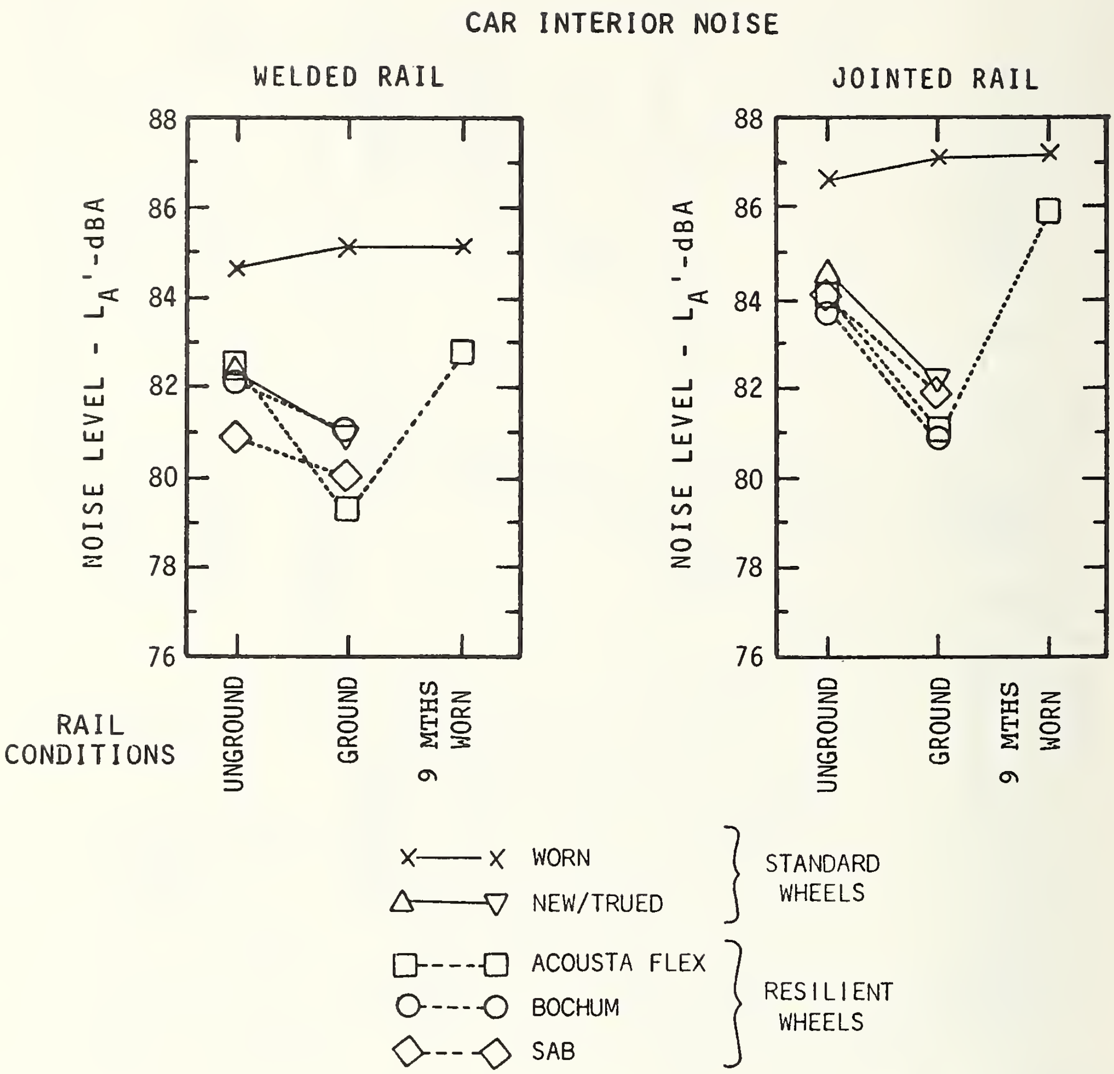


FIGURE 4.9. AVERAGE CAR INTERIOR NOISE LEVELS AT THE SUBWAY TEST TRACKS FOR VARIOUS WHEELS AND RAIL CONDITIONS

resilient wheels produce lower noise levels at the wayside and slightly lower in the car interior, particularly on the jointed test track. Also note that in some cases the noise level increases after the nine months wear period. However, on the TURN track both the squeal noise with the standard wheels and the general roar noise with the resilient wheels show a decrease after the nine months wear period.

Figure 4-10 presents the 1/3 octave band spectra of the wayside noise measured at the TURN track for the worn standard wheels and the two types of trued standard wheels. The charts show that the new or lathe turned wheels and the worn wheels have essentially the same spectrum shape for the squeal noise except that the new wheels produced about 4 dBA lower levels. The wheels after truing with the milling cutting type cutter truer resulted in a different spectrum with an additional peak at 2500 Hz. The maximum sound level in the 6300 Hz band remained the same as for the new wheels. The additional level due to the higher squeal level in the 630 Hz band and the additional squeal at the 2500 Hz band resulted in an increase in the overall level such that the A-weighted level was essentially the same as for the worn wheels. It is apparent that more normal modes of vibration were excited in the trued wheels than in either the new wheels or the worn wheels, possibly due to differences in the wheel/rail contact area or wheel/rail adhesion.

The overall evaluation of the effect of truing on tangent track is that the use of either a lathe type truing machine or a milling type truing cutter results in 2 to 4 dBA lower noise levels on welded track and similar reductions on jointed track. On short radius curved track, the lathe turned wheels result in about 4 dBA less squeal and the wheels trued with the milling cutter machine result in about the same overall squeal levels with a somewhat different spectrum.

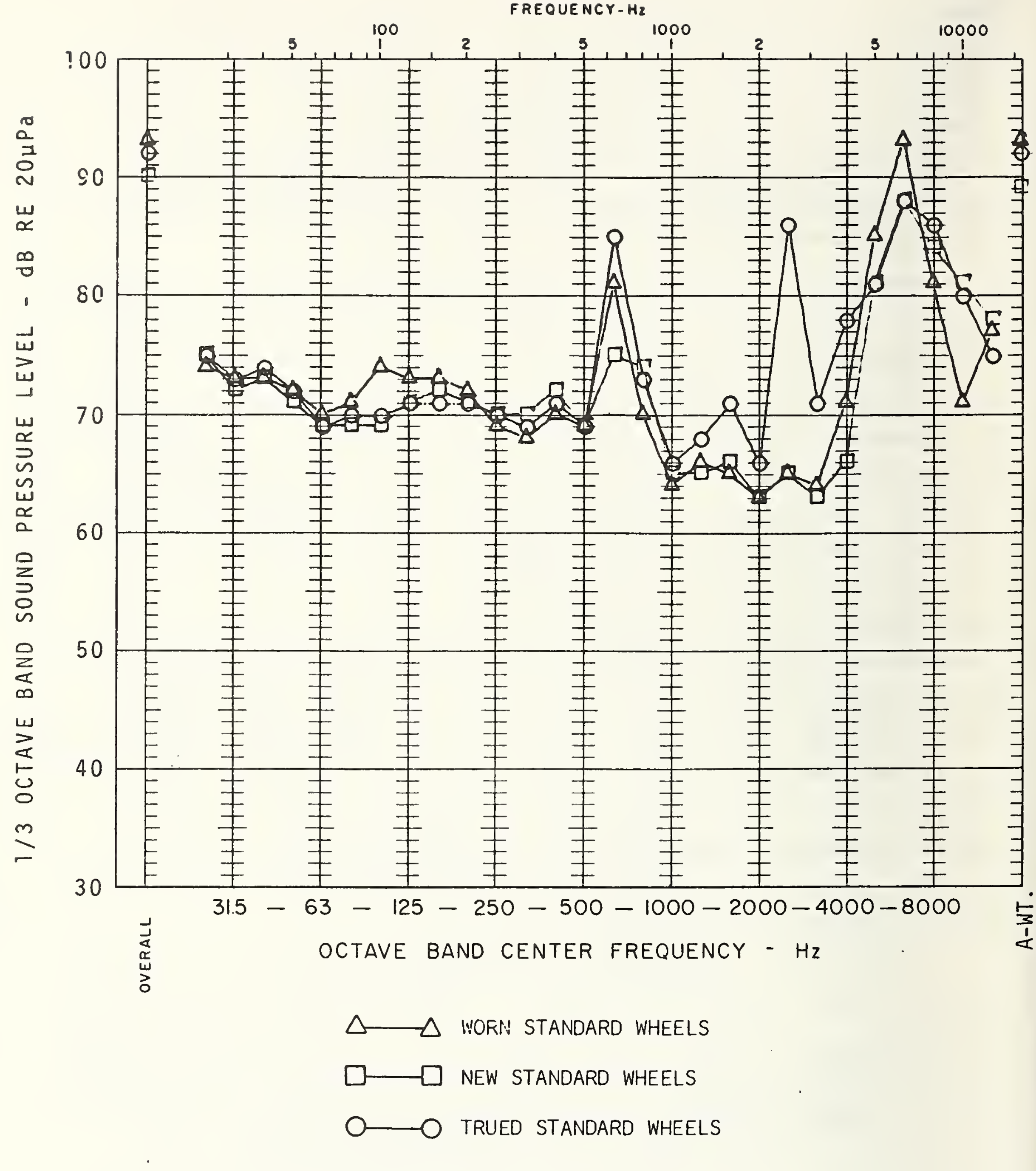


FIGURE 4-10. AVERAGE 1/3 OCTAVE BAND SPECTRA FOR WHEEL SQUEAL TESTS WITH STANDARD WHEELS ON THE TURN TEST TRACK

4.4 RESULTS FROM RESILIENT WHEELS

The effects of resilient wheels have been evaluated by measuring the wayside car interior noise with the three types of resilient wheels included in the study program. The wheels used for these tests were all in new condition and the tests reported herewith include the noise levels for ground and unground rail for all of the types of track included in the study, except for the short radius curve where only the ground rail conditions could be tested because of the fact that both the test and control track segments were ground after the Phase IA tests were completed.

Table 4-20 presents the average results for comparison of the wayside and car interior noise levels with each of the three varieties of resilient wheels - Acousta Flex, Penn Bochum and SAB wheels. In each case ,the table presents the data for comparison of the resilient wheels with the new/trued wheels operating on the same kind of track, i.e., where the resilient wheels were operating on ground rail,the comparison was made with the trued wheels operating on ground rail, etc. The purpose of comparing the resilient wheels with the trued wheels was to isolate the effect of the resilient wheels from other effects since all of the resilient wheels had new running surfaces at the beginning of the tests. The appropriate comparison for effect of only the resilient wheels is the comparison of the resilient wheels with the newest condition standard wheels.

Figures 4-6, 4-7, 4-8 and 4-9 in Section 4.3 also present in graphical form the average results of the wayside and interior noise data with the resilient wheels. The graphs show the comparison of the resilient wheel data with both the worn wheel and the new or trued standard wheels. The graphs also

TABLE 4-20. RELATIVE NOISE LEVELS FOR RESILIENT WHEELS COMPARED TO TRUED STANDARD WHEELS

Relative Noise Levels - dBA

Wheel Type	TW Track					
	Wayside Noise			Car Interior Noise		
	Unground Rail	Ground Rail	AVG	Unground Rail	Ground Rail	AVG
Acousta Flex	+0.1	-0.7	-0.3	-0.9	-0.9	-0.9
Bochum	+0.4	+0.3	+0.4	-1.2	-1.1	-1.2
SAB	-1.1	-0.9	-1.0	-1.9	-1.8	-1.8

Wheel Type	TURN Track					
	Wayside Noise			Car Interior Noise		
	Ground Rail	Worn Wheels & Rail	AVG	Ground Rail	Worn Wheels & Rail	AVG
Acousta Flex	-11.8	-13.3	-12.6	-3.2	-4.0	-3.6
Bochum	-11.6	-13.3	-12.5	-4.9	-4.0	-4.5
SAB	-5.1	-10.9	-8.0	+0.6	-2.8	-1.1

Wheel Type	TJ Track - Wayside Noise				
	Unground Rail	Unground & Aligned Rail	Ground Rail	Ground & Aligned Rail	AVG
Acousta Flex	-1.2	-2.9	-1.1	-2.2	-1.8
Bochum	-0.9	-1.6	-1.2	-2.9	-1.6
SAB	0.0	-0.7	-0.4	-1.1	-0.6

TABLE 4-20. (CONT'D)

Wheel Type	Relative Noise Levels - dBA				
	TJ Track - Car Interior Noise				
	Unground Rail	Unground & Aligned Rail	Ground Rail	Ground & Aligned Rail	AVG
Acousta Flex	-0.3	+0.5	-1.0	-2.7	-0.9
Bochum	-0.3	-0.6	-1.1	-1.8	-1.0
SAB	-0.2	-0.1	-1.3	-1.3	-0.7

Wheel Type	Subway Test Tracks					
	Car Interior Noise					
	Welded Rail			Jointed Rail		
	Unground Rail	Ground Rail	AVG	Unground Rail	Ground Rail	AVG
Acousta Flex	+0.3	-1.6	-0.6	-0.5	-1.0	-0.8
Bochum	-0.2	-1.8	-1.0	-0.9	-1.4	-1.2
SAB	-1.4	-0.9	-1.2	-0.5	-0.4	-0.4

Wheel Type	Subway Station Platform Noise Levels - dBA Welded Rail					
	Skip-Stop			Stop		
	Unground Rail	Ground Rail	AVG	Unground Rail	Ground Rail	AVG
Acousta Flex	+3.9	+1.2	+2.6	+3.6	-3.2	+0.2
Bochum	+2.4	+3.0	+2.7	+2.6	-4.1	-0.8
SAB	+2.8	-1.6	+0.6	+4.4	-0.6	+1.9

TABLE 4-20. (CONT'D)

Wheel Type	Relative Noise Levels - dBA	
	Elevated Station Platform Noise Levels - dBA Unground Jointed Rail	
	Skip-Stop	Stop
Acousta Flex	-0.6	+3.4
Bochum	-0.8	-1.4
SAB	-1.4	+0.6

show the results for the Phase III tests for those conditions where measurements were made after the nine months wear period. In the case of the TW test track, the results on the control track segment, which had further wear, and the ground rail segment, which had nine months wear, are separated to show the difference in results.

As is apparent from the tabular and graphical presentations of the data, in most cases the resilient wheels show substantially less noise than the standard worn wheels and about the same noise as the new or trued wheels. The noise reducing effect is most noticeable for the wayside noise on the tangent-jointed track, the car interior noise on the subway test track and for both the wayside and car interior noise for the TURN test track. Some of the data, particularly that for the tangent welded track, shows an increase of the noise after the wear period. After wear, the noise with the resilient wheels is not significantly different from that with the standard wheels on tangent track.

In general terms, the resilient wheels on the tangent welded track produce 0 to 2 dBA less wayside and car interior noise than the standard wheels and on the tangent-jointed track the resilient wheels produce 3 to 4 dBA less noise at the wayside and 1 to 2 dBA less noise in the car interior. On the subway station platforms, the new resilient wheels produce 4 to 5 dBA less noise than worn standard wheels on ground rail, but only 2 to 3 dBA less noise after the period and essentially the same noise as the new/trued standard wheels.

The most dramatic effect observed with the resilient wheels was the reduction of the squeal noise on the short radius TURN track. The resilient wheels were very effective in removing the high pitched 6 to 8 kHz squeal which is characteristic of the standard wheels. The Acousta Flex and Bochum

wheels removed virtually all squeal, however, the SAB wheels tended to squeal at an additional frequency, about 1200 Hz, which resulted in less effectiveness in reducing the overall A-weighted sound level.

Table 4-21 presents an overall summary of the average A-weighted levels relative to the *worn* wheels for each test wheel type on the TURN test section. The purpose of this table is to show the dramatic effectiveness of the resilient wheels in reducing wheel squeal noise when compared to the worn standard wheels, the noisiest in terms of squeal produced on the TURN test track.

TABLE 4-21 RELATIVE NOISE LEVELS FOR THE TEST WHEELS COMPARED TO THE WORN STANDARD WHEELS - GROUND RAIL

Wheel Type	Relative Noise Levels - dBA	
	Wayside Noise	Interior Noise
New Standard	-3.2	-2.8
Acousta Flex	-12.5	-3.4
Bochum	-12.3	-5.2
SAB	-5.8	-0.2

The Acousta Flex and Penn Bochum wheels reduce wayside noise 12 dBA ,although the car interior noise was reduced only 3 and 5 dBA, respectively. These figures may be somewhat deceptive because the subjective difference between the standard wheels and the Acousta Flex and Penn Bochum wheels is very large due to the reduction in the intensity of the pure

tone components. In community noise evaluation, it is typical to add a 5 dBA penalty to noise that contains significant pure tone components. However, such a simple procedure is not adequate for this study, particularly since all the wheels created some squeal.

To indicate more detail on the wheel squeal noise, the average 1/3 octave band spectra for each train are presented in Figures 4-11 through 4-16. The first three, Figures 4-11, 4-12 and 4-13, show the average wayside spectra for the control segment and test segment of the TURN track and the combination of the two segments, respectively. These averages have been calculated on an energy basis rather than arithmetically, hence each data plot is equivalent to the RMS level for one long sample.

The second group of three figures, Figures 4-14, 4-15 and 4-16,are the average of the interior samples on the control segment, the test segment and the two combined. In this case,the final average spectra includes both arithmetic and energy averages. First for each test the data in the car center and over the truck were averaged arithmetically, then all of the samples for each train were energy averaged.

The 1/3 octave band plots show very clearly the intense squeal that occurs at 6 to 8 kHz with the standard wheels. This peak is 28 to 30 dBA higher than the levels at the same frequency with the resilient wheels. Clearly with the standard wheels the 6 to 8 kHz squeal dominates the wayside and interior A-weighted sound levels.

Referring to Figures 4-14, 4-15 and 4-16 showing the car interior average 1/3 octave band levels, it is evident that the resilient wheels have a very strong influence on the character of the noise. With all of the resilient wheels the the intense 6 to 8 kHz squeal is completely removed. The SAB

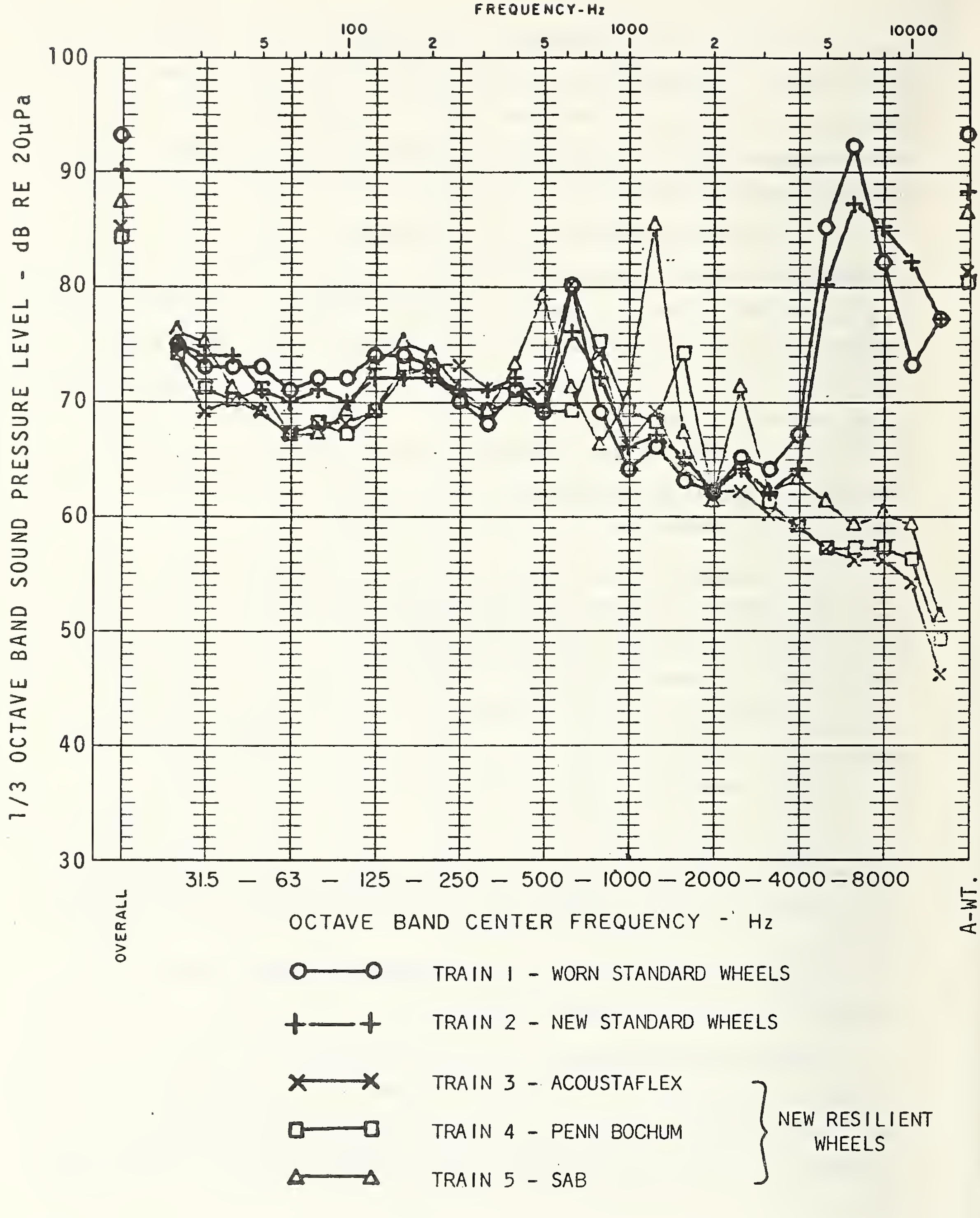


FIGURE 4-11. AVERAGE WHEEL SQUEAL LEVELS FOR TURNAROUND - CONTROL SEGMENT - WAYSIDE NOISE

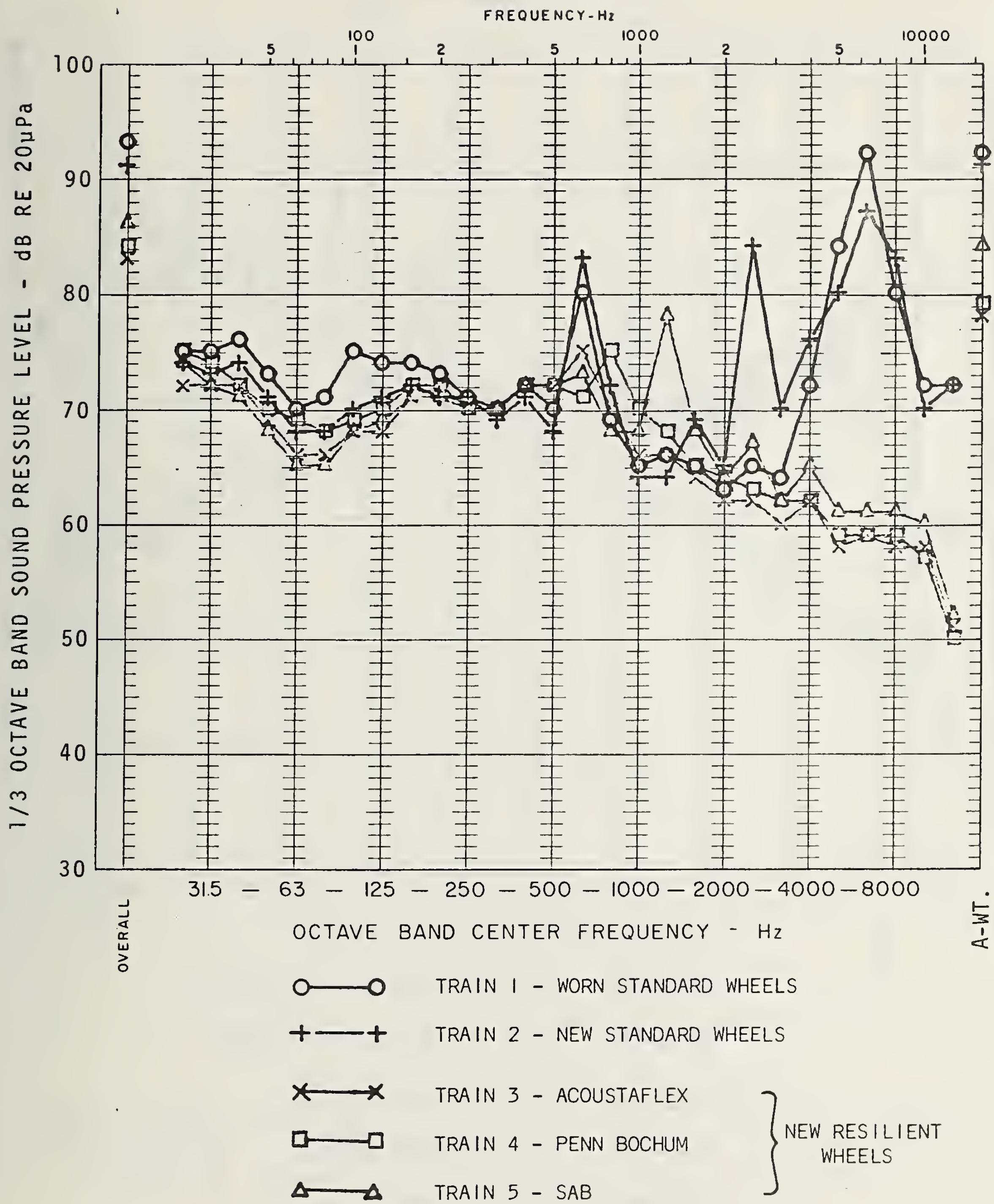


FIGURE 4-12. AVERAGE WHEEL SQUEAL LEVELS FOR TURNAROUND - TEST TRACK SEGMENT - WAYSIDE NOISE

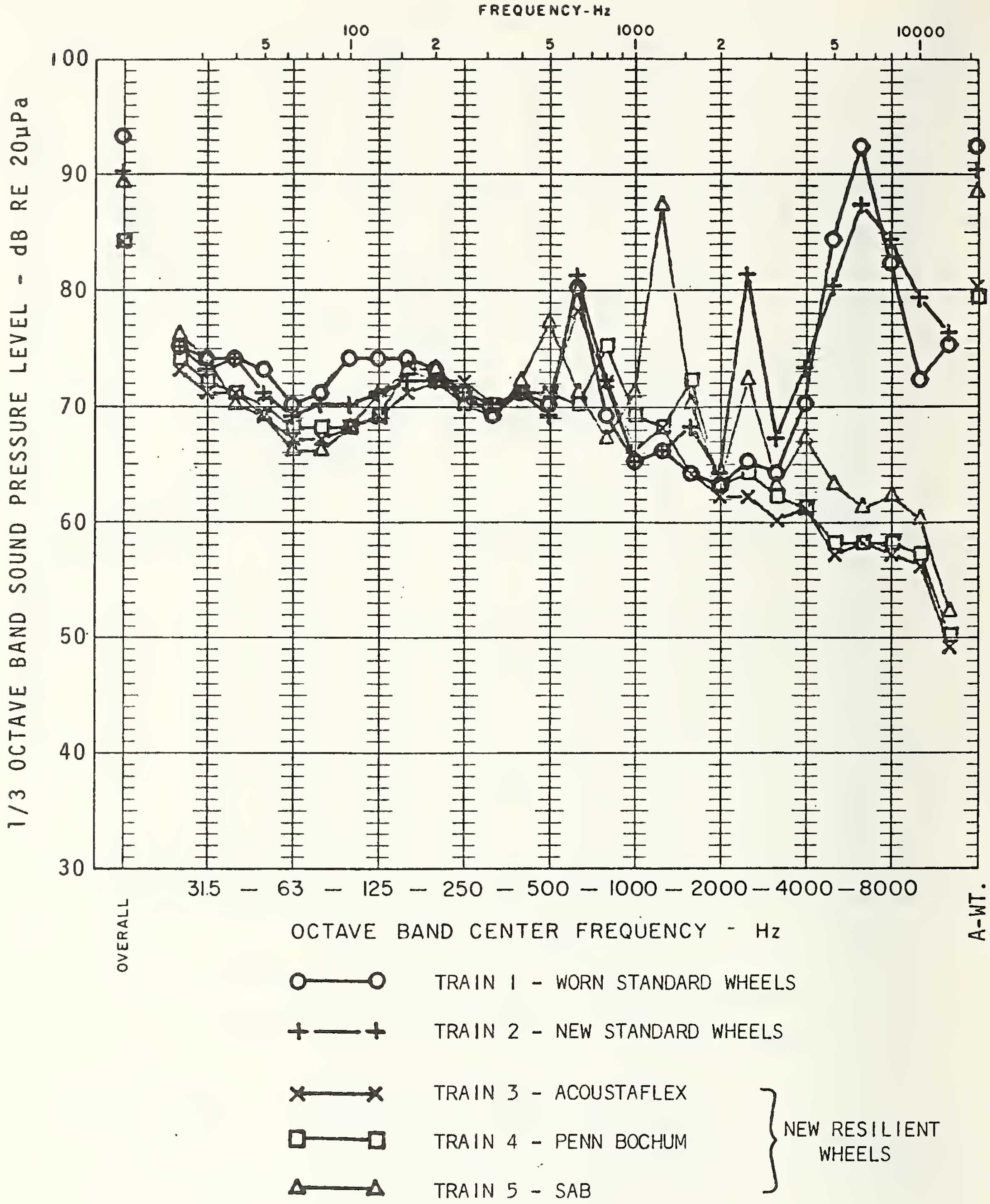


FIGURE 4-13. AVERAGE WHEEL SQUEAL LEVELS FOR PHASES I AND II TURNAROUND MEASUREMENTS, BOTH TRACK SEGMENTS - WAYIDE NOISE

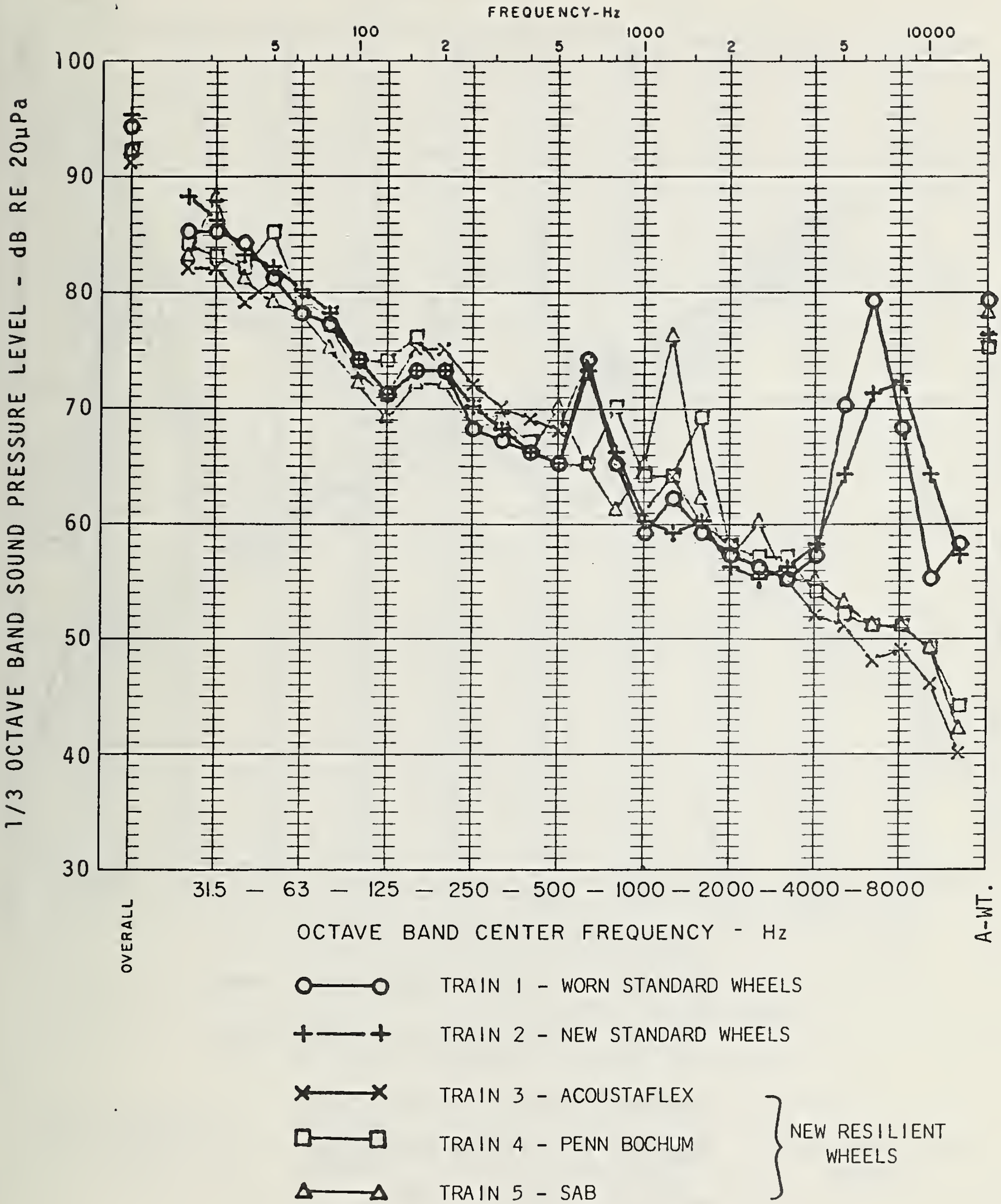


FIGURE 4-14. AVERAGE WHEEL SQUEAL LEVELS FOR TURNAROUND MEASUREMENTS - CONTROL TRACK SEGMENT - CAR INTERIOR NOISE

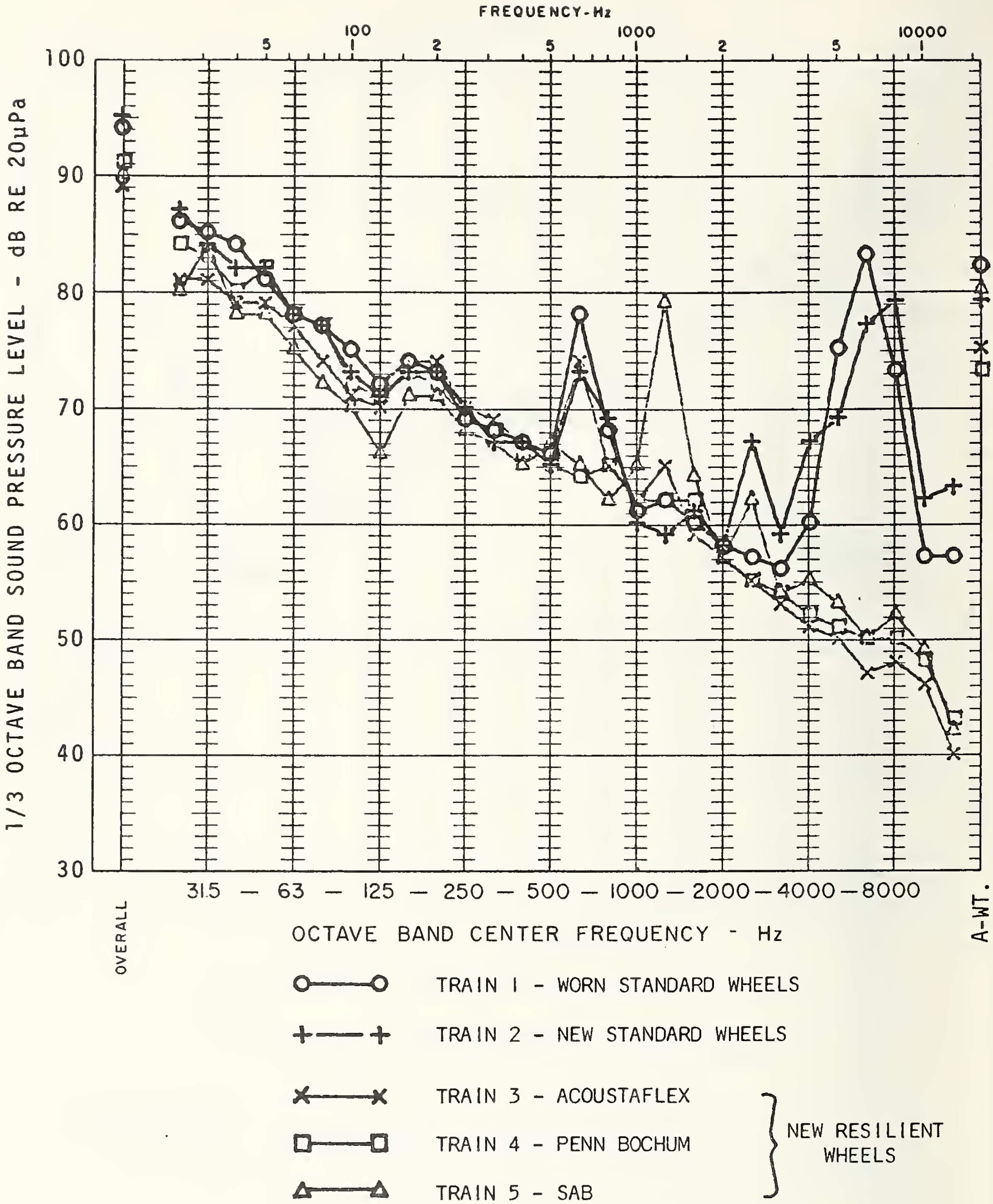


FIGURE 4-15. AVERAGE WHEEL SQUEAL LEVELS FOR TURNAROUND MEASUREMENTS - TEST TRACK SEGMENT - CAR INTERIOR NOISE

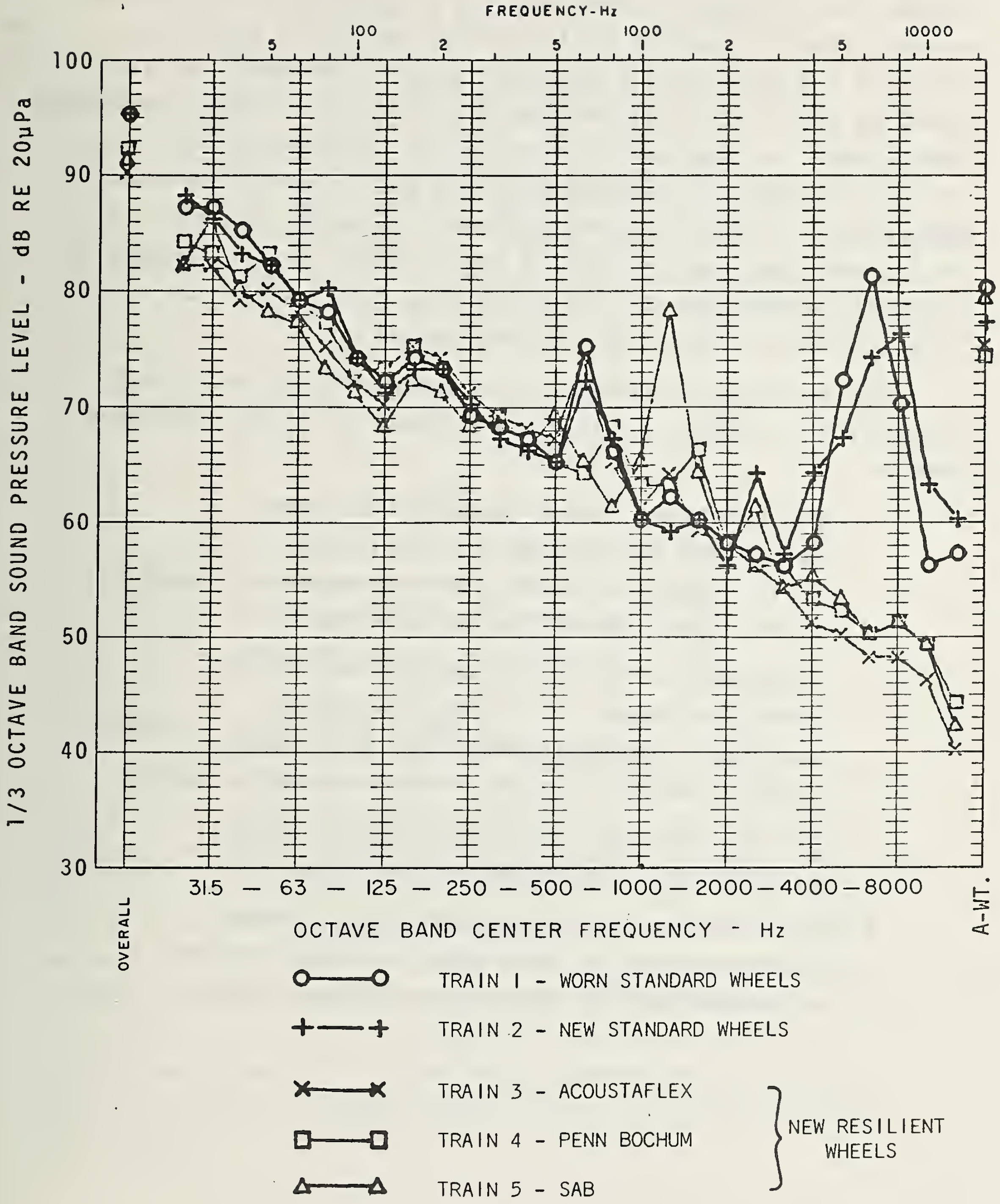


FIGURE 4-16. AVERAGE WHEEL SQUEAL LEVELS FOR PHASES I AND II TURNAROUND MEASUREMENTS, BOTH TRACK SEGMENTS - CAR INTERIOR NOISE

wheels have a squeal in the 1250 Hz 1/3 octave band that dominates the A-weighted level and the Acousta Flex wheels have a small peak in the 600 Hz 1/3 octave band that does not strongly influence the A-weighted levels. However, as indicated by Table 4-21 the average car interior overall A-weighted levels show the SAB wheels essentially the same as the worn standard wheels,the new standard and the Acousta Flex wheels equivalent and the Penn Bochum wheels somewhat quieter. It is evident that the A-weighted levels alone do not reflect a realistic evaluation of the subjective loudness of the car interior noise levels due to wheel squeal.

Following is a summary of the observations and conclusions from the Phase I, II and III tests with the resilient wheels.

a. The resilient wheels produce only small reductions of wayside or in-car noise (0 to 2 dBA) on either tangent welded or jointed track - particularly after some wear.

b. In subway on tangent track the resilient wheels produced 2 to 5 dBA less noise than worn standard wheels but only about 1 dBA less than the new/trued standard wheels.

c. At station platforms the resilient wheels produced no significant noise reduction.

d. The resilient wheels dramatically change the character of the squeal sound on curves. Although they do create some squeal noise

in the frequency range of 1000 to 2000 Hz, the high frequency squeal characteristic (6000 to 8000 Hz) of the standard wheels is entirely removed. With both the Acousta Flex and Penn Bochum wheels the remaining squeal noise was very intermittent and at much lower levels than with the standard wheels. The SAB wheels had relatively high levels of squeal although the wayside levels were still significantly lower than the standard wheels.

e. Wheel squeal can be quite erratic. The variations in the average level between test Phases IB and IC with the worn standard wheel train where none of the control variables were changed was 4 dBA and the range of observed levels for different passbys with the same train in one test series were as high as 16 dBA.

4.5 RESULTS AT FROG TEST TRACK

In Phase IIB measurements were taken of the noise levels over a frog at the crossover just east of the 63rd Street Station. At this location, the track is on elevated structure with a ballast and timber tie trackbed. With each of the five trains, six passbys were made over the frog at speeds between 40 and 80 km/hr. Due to the proximity of the 63rd Street Station and the curve west of the 63rd Street station, it was difficult for the train operators to maintain the desired speed, hence the speeds were somewhat more variable than was the case for the measurements on the other tangent test tracks.

The data analysis procedure for the frog test track data was the same as for the other test tracks, utilizing the rms average of the maximum noise levels during the train passage over the frog. The average values of L_A' and corresponding data standard deviations are presented in Table 4-22.

The levels for each test train relative to the worn standard wheel test train are summarized in Table 4-23. The data indicate that the various types of wheels result in only marginally different noise levels for operation over the test frog. At the wayside location the resilient wheels averaged 2.0 dBA quieter than the worn standard wheels and the trued standard wheels averaged 1.1 dBA quieter than the worn standard wheels. Use of a standard Student's "t" test to compare means indicates that the differences between worn and trued wheels and between the worn and resilient wheels are significant at the 95 percent level. Hence, the statistics indicate that the noise reductions at the frog with resilient wheels and trued wheels are significant even though a noise level reduction of 2 dBA will not result in a noticeable improvement in the community impact.

The differences between the car interior average L_A' levels are smaller than observed at the wayside, the trued wheels averaging 0.6 dBA quieter than the worn standard wheels and the resilient wheels averaging 0.4 dBA quieter than the worn standard wheels. These differences are not sufficient to be statistically significant.

TABLE 4-22. AVERAGE A-WEIGHTED SOUND LEVELS - L_A'-dBA - FROG TEST TRACK

Wheel Type	Wayside Noise	Car Interior Noise
Worn Standard	92.6 *(0.6)	81.7 (1.8)
Trued Standard	91.5 (1.2)	81.1 (1.2)
Acousta Flex	90.5 (1.1)	82.4 (1.4)
Bochum	90.6 (1.6)	83.0 (1.2)
SAB	90.7 (0.7)	81.0 (1.2)
AVERAGE	91.1	81.8

* Numbers in parentheses () are the data standard deviations.

TABLE 4-23. AVERAGE NOISE LEVELS AT THE FROG RELATIVE TO THE WORN WHEEL LEVELS

Wheel Type	Wayside Noise	Car Interior Noise
Trued Standard	-1.1	-0.6
Acousta Flex	-2.1	+0.7
Bochum	-2.0	+1.3
SAB	-1.9	-0.7

4.6 DISCUSSION OF TEST RESULTS

The previous sections have presented and discussed the results from rail grinding, wheel truing and resilient wheels as individual noise reduction procedures applied to the SEPTA vehicles and facilities. Tables 4-24 and 4-25 present the results from the combined effect of all the noise reduction treatments for wayside noise and car interior noise, respectively. The tables show the combined effects for wheel truing and rail grinding and for resilient wheels which are in the new or trued condition combined with rail grinding. These results can be compared with the tabulated results in Sections 4.2, 4.3 and 4.4 to find the effect of combined procedures compared with the effects of the individual noise reduction procedures.

Tables 4-24 and 4-25 are overall averages of all of the data with the appropriate corrections for normalizing the results included in calculating the average. For the subway station platform noise levels, the average is for both the skip-stop and stop operations, as measured. The reference in each case is the worn standard wheels on unground rail in order to provide a direct comparison of the combined effects of applying all three of the noise reduction procedures to the existing facilities.

For the short radius curve track, the A-weighted car interior sound level showed only small reduction with the resilient wheels, but there was a very large reduction of the squeal components of the sound, on the order of 25 to 30 dBA reduction in the high frequency squeal sound.

It is apparent from the comparison of these overall figures on Tables 4-24 and 4-25 with the results from the individual noise reduction features that, as measured with the SEPTA vehicles and facilities, the noise reduction

TABLE 4-24. RELATIVE SOUND LEVELS WITH COMBINED NOISE REDUCTION METHODS - REFERENCED TO WORN STANDARD WHEELS ON UNGROUND RAIL - WAYSIDE NOISE

Wheel Type	Relative Sound Levels - dBA				
	TW Ground Rail	TJ Ground Rail	TJ Ground & Aligned Rail	TURN Ground Rail	Subway Station Ground Rail
New Standard-Lathe Turned	-1.5	--	--	-2.5	--
Trued Standard	-0.1	-4.0	-4.0	+0.1	-0.4
Acousta Flex	-1.8	-5.1	-6.0	-11.8	-1.6
Bochum	-1.1	-5.2	-6.9	-11.6	-0.9
SAB	-2.1	-4.4	-5.2	-5.1	-1.9
Average Standard	-0.8	-4.0	-4.0	-1.2	-0.4
Average Resilient	-1.7	-4.9	-6.0	-9.5	-1.5

Above values are averaged results for all similar condition tests.

TABLE 4-25. RELATIVE SOUND LEVELS WITH COMBINED NOISE REDUCTION METHODS - REFERENCED TO WORN STANDARD WHEELS ON UNGROUND RAIL - CAR INTERIOR NOISE

Wheel Type	Relative Sound Levels - dBA					
	TW Ground Rail	TJ Ground Rail	TJ Ground & Aligned Rail	SUB 1 Ground Welded Rail	SUB 2 Ground Jointed Rail	TURN Ground Rail
New Standard - Lathe Turned	-4.8	--	--	--	--	-2.3
Trued Standard	-2.1	-1.7	-1.7	-3.7	-4.4	+0.5
Acousta Flex	-2.7	-2.7	-4.4	-5.3	-5.4	-2.7
Bochum	-2.9	-2.8	-3.5	-5.5	-5.8	-4.3
SAB	-3.6	-3.0	-3.0	-4.6	-4.8	+1.1
Average Standard	-3.5	-1.7	-1.7	-3.7	-4.4	-0.9
Average Resilient	-3.1	-2.8	-3.6	-5.1	-5.3	-2.0

from the individual noise reduction procedures do not add directly to give a significantly larger noise reduction from a combination of noise reduction procedures. For example, for tangent track rail grinding produces about 2 dBA noise reduction in some cases; wheel truing produces about 2 dBA noise reduction in some cases; but the combination of the two still produces only about 2 dBA noise reduction.

Table 4-26 presents the average A-weighted difference between the noise levels on jointed and welded track for the Phase I and Phase II measurements. For the standard wheels, the difference is significantly greater at the wayside than inside the cars. The resilient wheel tests indicate the same average difference on the ballast and tie track for the wayside and car interior noise levels.

TABLE 4-26. AVERAGE SOUND LEVELS ON TANGENT WELDED TRACK RELATIVE TO TANGENT JOINTED TRACK

Wheel Type	Ballast and Tie Track		Subway
	Wayside	Car Interior	Car Interior
Worn Standard	-5.1 dBA	-2.7 dBA	-2.0 dBA
New Standard	-6.1	-2.9	-1.8
Acousta Flex	-3.6	-3.6	-2.1
Penn Bochum	-2.9	-3.6	-1.6
SAB	-5.4	-4.4	-2.5
AVERAGE STANDARD	-5.6	-2.8	-1.9
AVERAGE RESILIENT	-4.0	-3.9	-2.1

To show the characteristic spectrum of the wayside noise for the SEPTA vehicles with the various types of wheels and for unground and ground rail, Figures 4-17 and 4-18 present the 1/3 octave band analysis of the average wayside noise for the trains with trued standard wheels and the three types of resilient wheels with the train passing by at nominally 60 km/hr on the tangent welded track. It is apparent from these two graphs that on the unground rail the trued wheels and the resilient wheels give essentially the same noise spectrum except for low frequency - below 250 Hz - whereas on the ground rail, the resilient wheels show a generally lower spectrum for the entire frequency range. These data were taken at the same test time, during the Phase IIA tests, and represent the data from the control track segment and the test track segment for unground and ground rail, respectively. Therefore, there may be other differences, but these data represent the best available comparison for wayside noise for before/after rail grinding and standard versus resilient wheels.

One factor in the car interior data which was, at first, thought to be of possible significance was a wind noise and whistle which was apparent in some data recordings. This noise created a peak at 8000 Hz and occasionally a second peak at 2000 Hz. The peak at 8000 Hz was of low enough level that it did not affect the A-weighted sound level. However, the 2000 Hz peak was of sufficient level that it could affect the A-weighted sound level result.

Referring to the car interior tangent track spectra presented in the appendices, it is evident that this wind noise influenced about 15% to 25% of the samples. If this noise does affect the A-weighted levels, then the averages that have been calculated could result in drawing erroneous

conclusions about the performance of the noise reduction treatments. This possibility was investigated for the Phase IA measurements on the ballast and tie tangent welded test track. In Phase IA the peak at 2000 to 3000 Hz occurred in about three of the six worn wheel train data sets and only once in the new wheel train data. The 1/3 octave band spectra for the six worn wheel data sets are shown in Figure 4-19. The apparent wind noise in the 2000 Hz 1/3 octave band is evident in three of the data curves.

To determine the effect of this noise on L_A' the A-weighted levels for each data set were calculated with the whistle noise peaks removed. The net effect was reduction of the dispersion of the data points relative to the best fit straight line on a level versus speed plot when the influence of the peak is removed. Looking at the average values of L_A' for both the corrected and uncorrected data, correcting the three data sets with the peak reduces the variance from 0.69 to 0.36 - an indication that the wind noise is responsible for some of the dispersion of the car interior data observed in the measurements. However, the actual values of L_A and L_A' are not changed much and the average values of L_A' are changed by an insignificant amount - from 79.6 dBA with the peak to 79.4 dBA without the peak.

The conclusion that can be drawn is that although the car interior A-weighted noise levels were occasionally influenced by the "wind" noise, the influence on the average level of L_A' is minimal and will not have any influence on the conclusions drawn from the data.

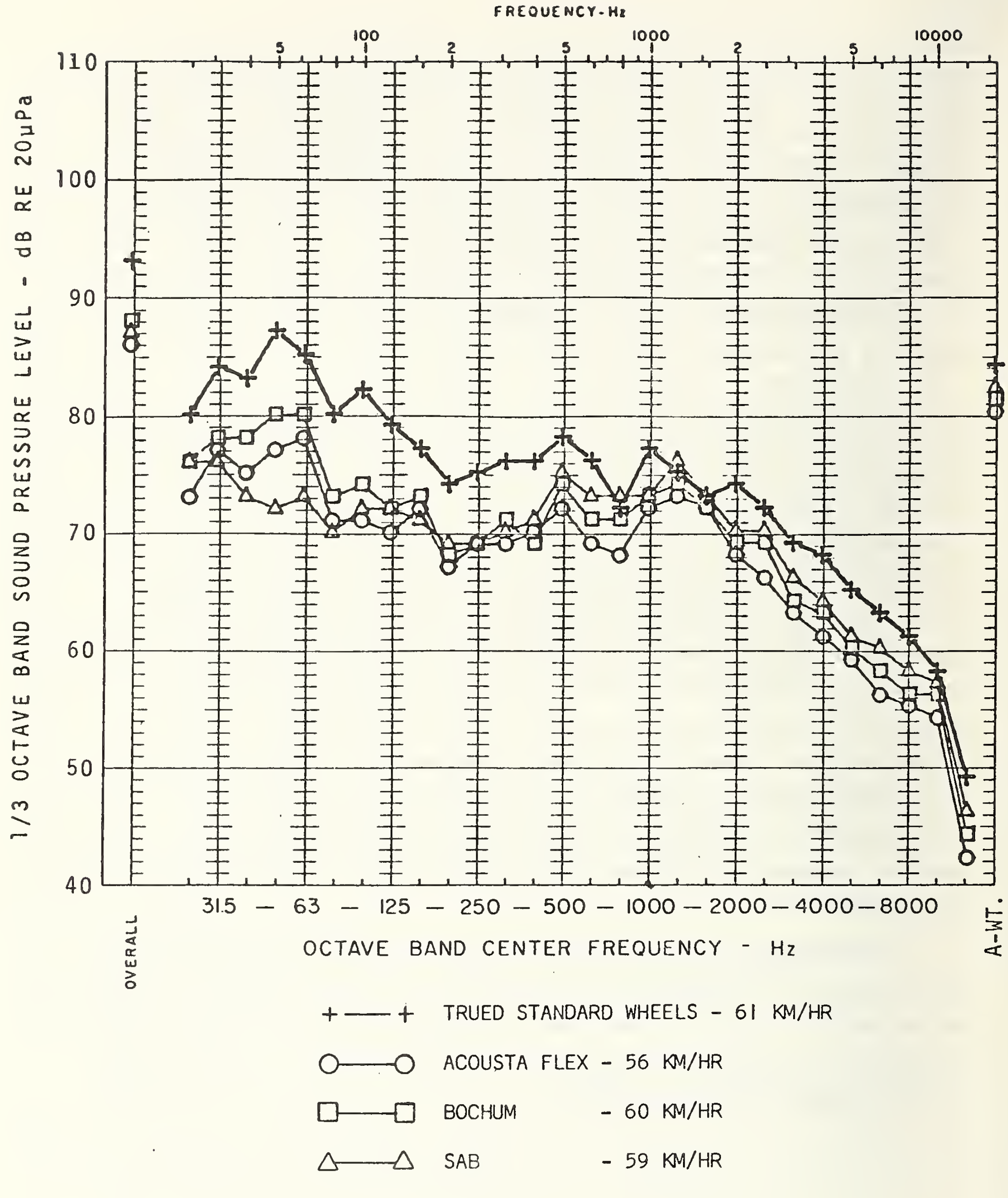


FIGURE 4-17. WAYSIDE NOISE LEVELS ON BALLAST AND TIE-WELDED TRACK GROUND RAIL - 60 KM/HR NOMINAL SPEED

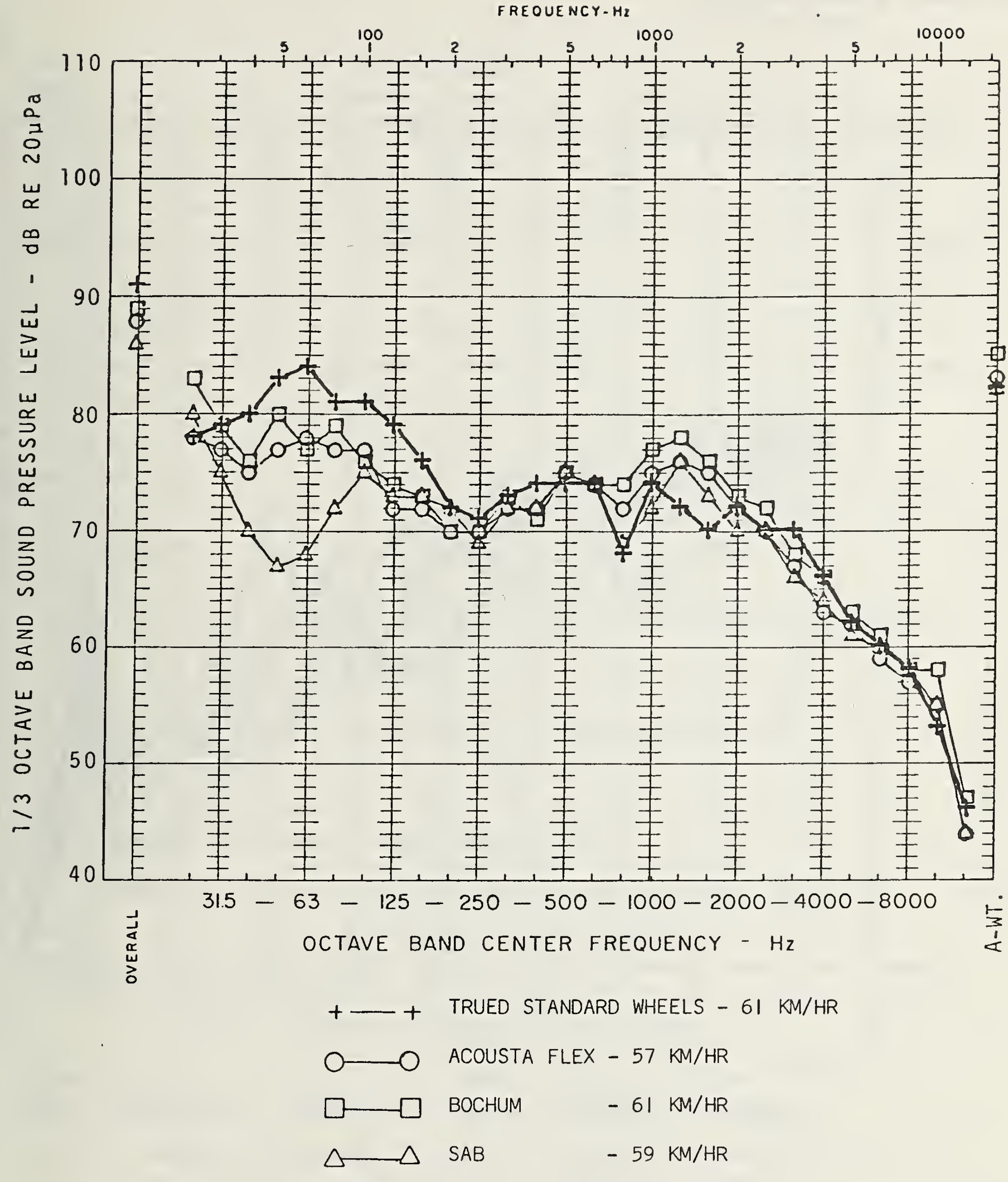
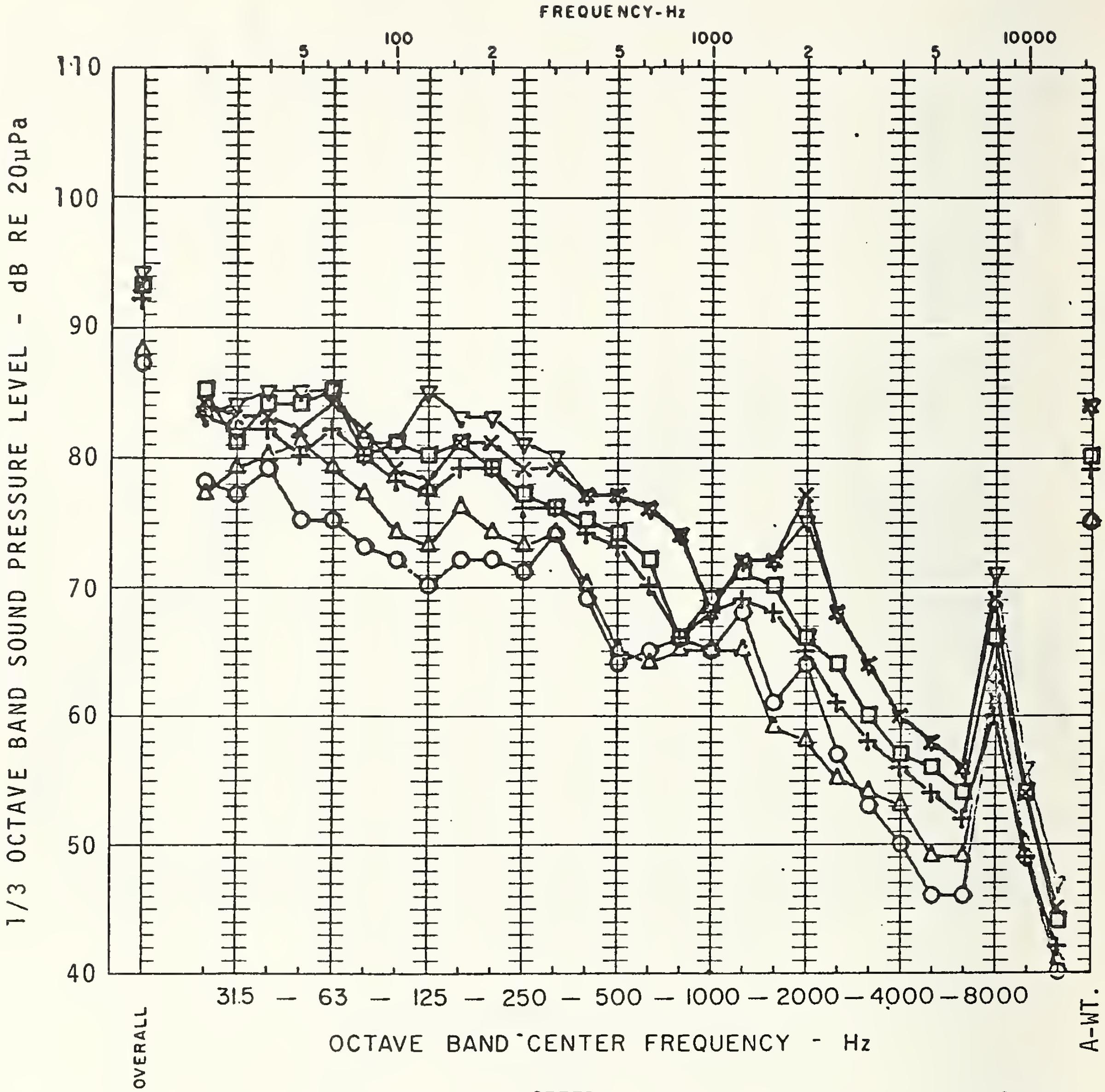


FIGURE 4-18. WAYSIDE NOISE LEVELS ON BALLAST AND TIE-WELDED TRACK UNGROUND - 60 KM/HR NOMINAL SPEED



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	NORMAL	75	○——○	NORMAL	41
+——+	REVERSE	56	△——△	REVERSE	42
□——□	NORMAL	62	▽——▽	NORMAL	78

FIGURE 4-19. CAR INTERIOR LEVELS INFLUENCED BY WIND NOISE - TANGENT-WELDED BALLAST-AND-TIE TEST TRACK - PHASE IA: CAR INTERIOR OVER TRUCK - WORN STANDARD WHEELS

The analysis of tangent track data presented in the previous sections of this report has all been in terms of average L_A'. As discussed previously, L_A' represents the A-weighted level normalized to 60 km/hr assuming noise level is proportional to 30 *log* (speed). The factor of 30 closely approximates the speed dependence displayed by the majority of the data.

Figure 4-20 presents the A-weighted levels as a function of speed from the Phase IIB tests on the TJ A and B test tracks. These are the two jointed test sections that were ground before the Phase IIB testing. Also shown on Figure 4-20 are the best fit straight lines for the interior and wayside data, both of which have a slope very close to 30. From the relatively tight grouping of the data points around the best fit lines it is evident that the straight line representation is fairly accurate. Note that the wayside levels of the worn standard steel wheel train are consistently 1 to 4 dBA above the average levels with the other four trains, a fact reflected in the analysis of L_A'. This is an indication of the accuracy of using L_A' to evaluate the results. For the points on Figure 4-20, the average value of wayside L_A' is 3.5 dBA higher for the worn standard wheel train than for the average of the other four trains.

There were some specific tests where the data did not show a 30 *log* (speed) dependence. In particular, the speed dependence of the wayside levels on the TW test track is more closely approximated by a factor of 40 and the interior levels on the FROG test track were more closely approximated by a factor of 20. Figure 4-21 presents the A-weighted levels from the Phase IIA tests on the two TW test tracks and Figure 4-22 presents the Phase IIB results on the FROG test track. Once again the best fit straight lines tend to accurately reflect the speed dependence of the data.

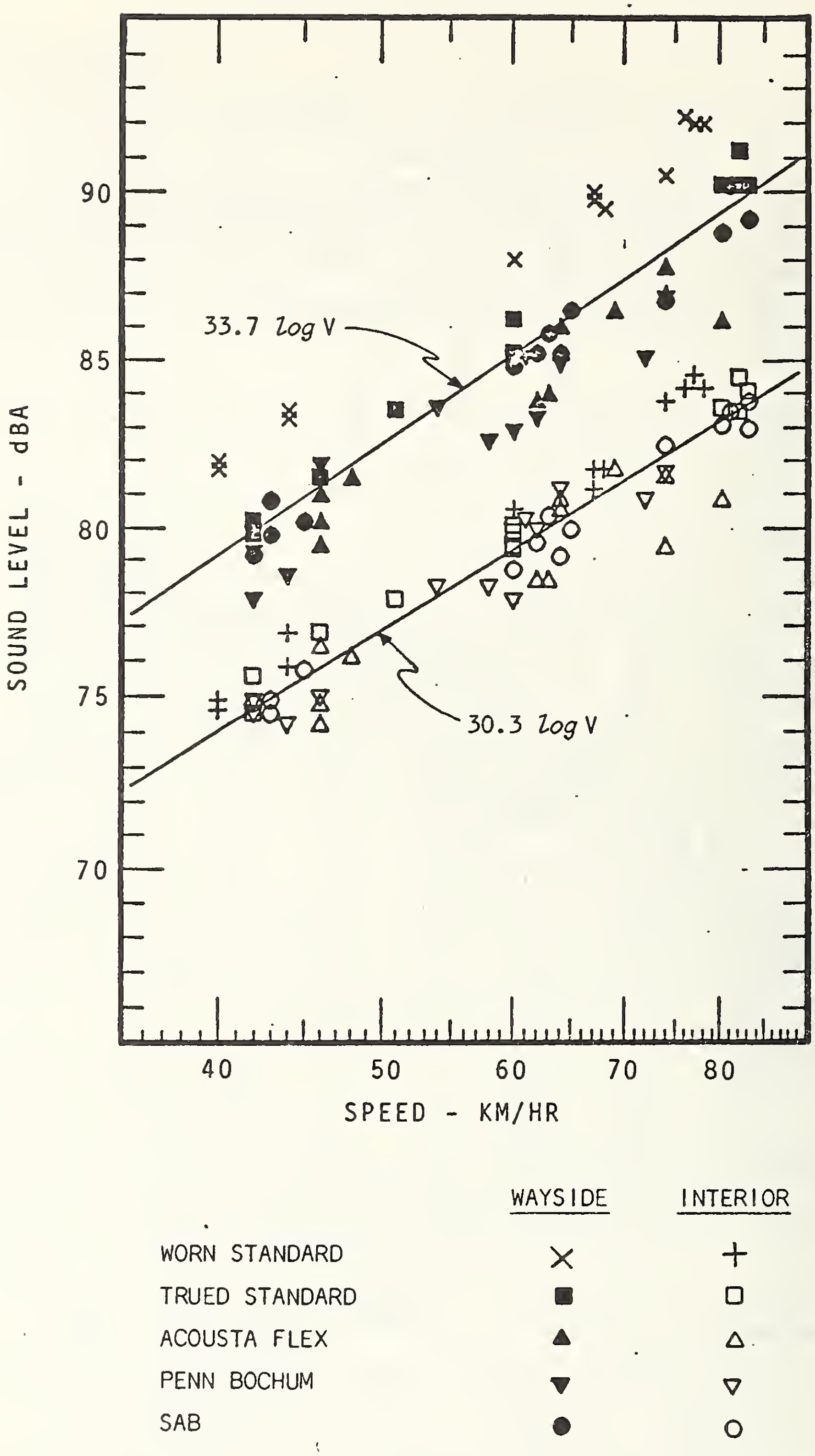


FIGURE 4-20. A-WEIGHTED NOISE LEVELS ON RECENTLY GROUND TJ TEST TRACKS, PHASE IIB. (JOINTED TRACK ON BALLASTED ELEVATED STRUCTURE)

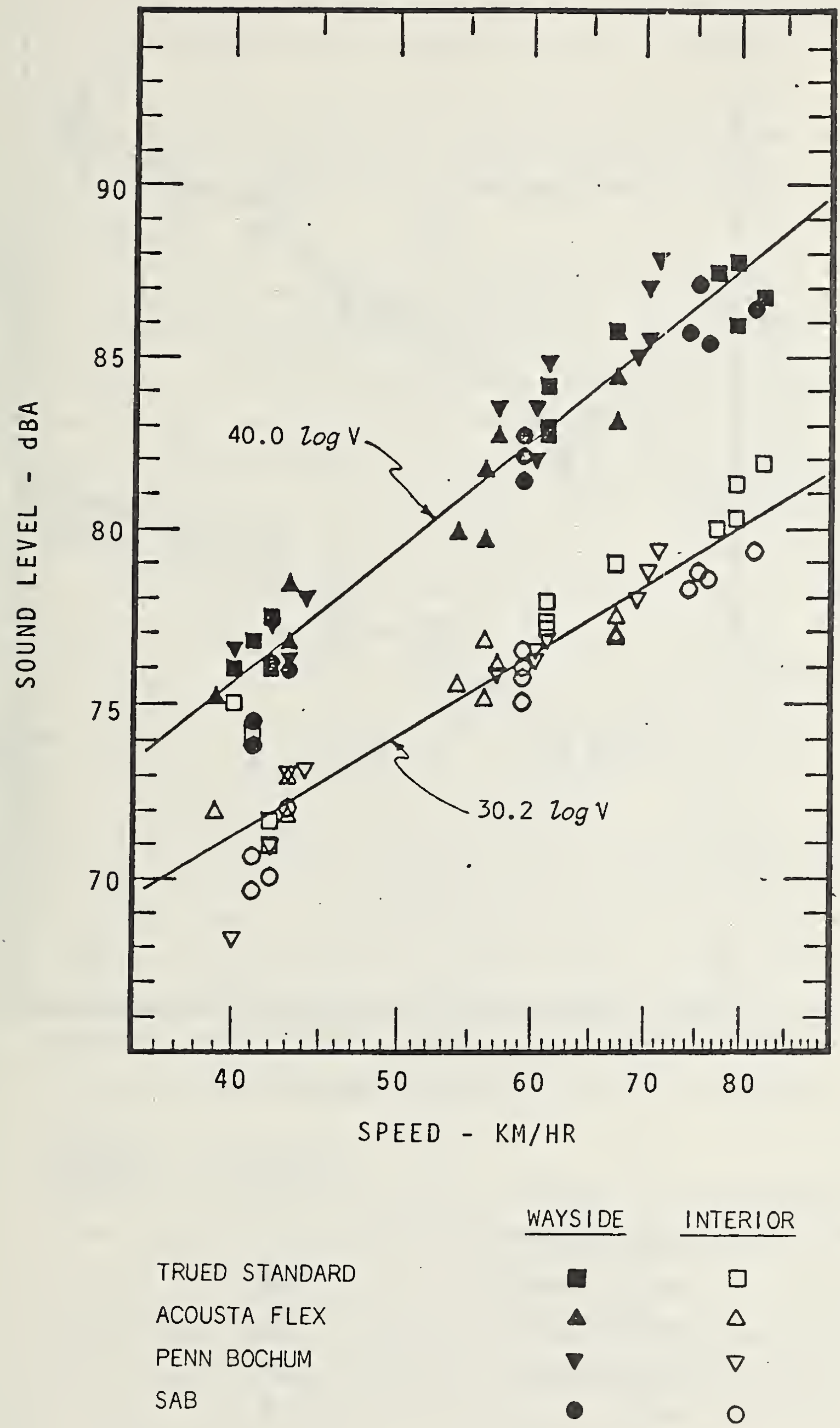


FIGURE 4-21. A-WEIGHTED NOISE LEVELS ON TW TEST TRACK, PHASE IIA. (TANGENT WELDED TRACK ON BALLASTED ELEVATED STRUCTURE)

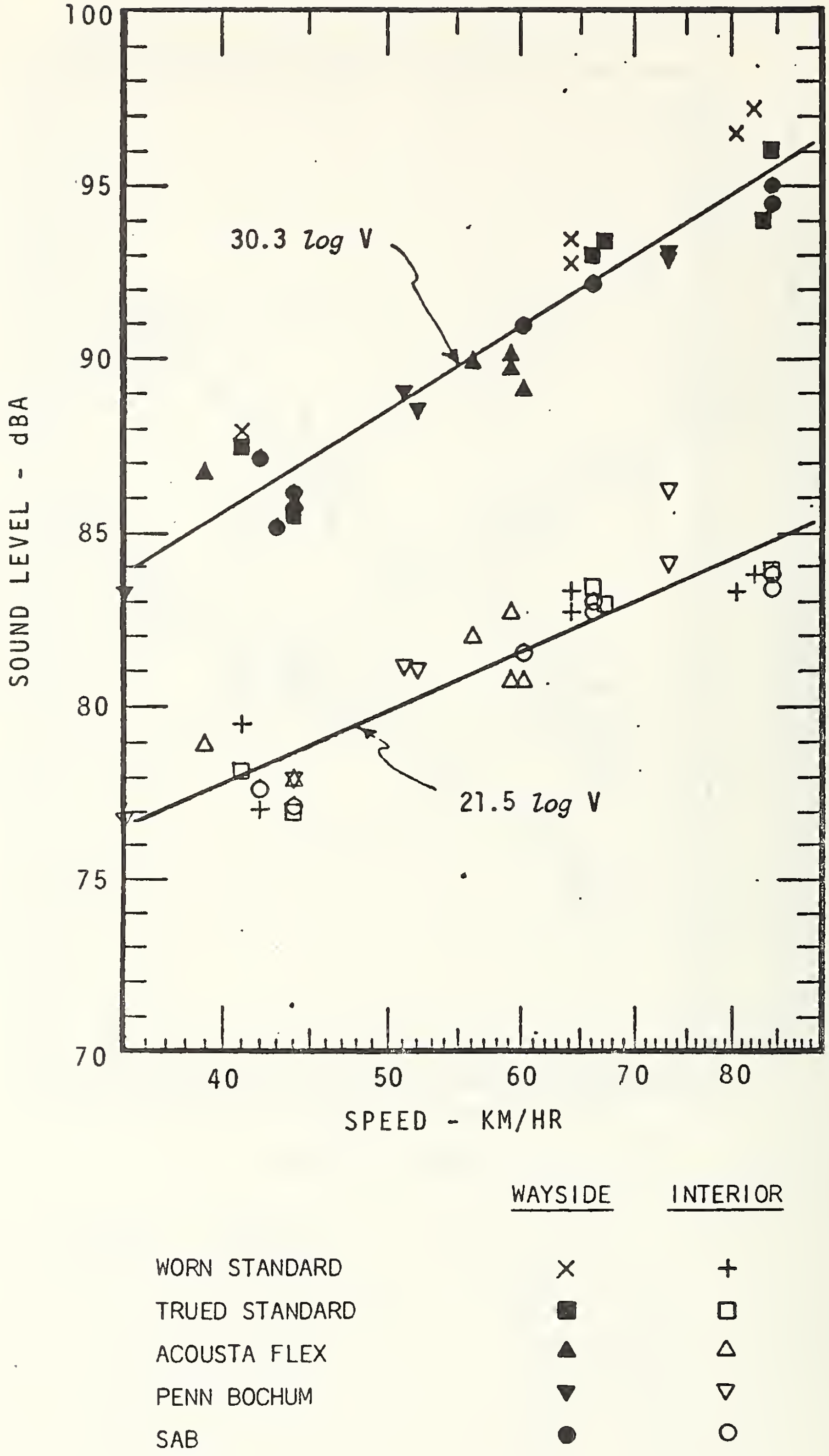


FIGURE 4-22. A-WEIGHTED NOISE LEVELS ON FROG TEST TRACK

The speed dependence factors on the elevated structure ballast and tie tangent test tracks indicate that:

a. In the speed range of 40 to 80 km/hr, the difference between car interior levels on jointed and welded track is not a function of speed.

b. The difference between wayside noise levels on jointed and welded track is a function of speed. For the curves shown in Figures 4-20 and 4-21, the difference between jointed and welded wayside levels varies from about 4 dBA at 40 km/hr to approximately 1 dBA at 80 km/hr. One possibility is that the wayside noise levels on the TW test track are dominated by wheel/rail noise at low speeds (40 to 60 km/hr) and by propulsion machinery noise at the higher speeds.

Comparison of the FROG data, Figure 4-22, and the TJ data, Figure 4-20, shows that:

1. The impact noise from the frog results in noise levels significantly higher than on the tangent jointed track. At the wayside the level at the FROG was approximately 6 dBA higher, and inside the car approximately 2 dBA higher. This shows that the frog impacts have a stronger influence on the wayside levels than on the car interior levels.

2. The frog impact noise increases the car interior noise level more at low speeds than at high speeds.

All of the analysis presented in the previous sections of this report have been performed using a speed normalizing factor of 30. The TW wayside data from Phase IIA (Figure 4-21) has a true slope closer to 40 than to 30. For this data the average values of L_A' have been calculated using

normalizing factors of both 30 and 40. Table 4-27 summarizes the results. The results show that using the normalization factor of 40 has a very small effect on the average values. The average values of L_A' are consistently lower when using a normalizing factor of 40, however, the maximum difference in average L_A' is -0.4 dBA. The primary effect of using a normalizing factor of 30 instead of 40 is that the standard deviations are larger. Such a result indicates that there is an unrealistically large spread of the values around the mean value.

TABLE 4-27. COMPARISON OF NORMALIZED WAYSIDE NOISE LEVELS ON TW TEST TRACKS USING DIFFERENT NORMALIZING FACTORS

Train	Normalizing Factor				Difference $\Delta L_A'$
	30		40		
	Average L_A'	Standard Deviation	Average L_A'	Standard Deviation	
Trued Standard	82.7	1.0	82.8	0.6	-0.1
Acousta Flex	82.4	0.9	82.8	0.7	-0.4
Penn Bochum	83.2	1.4	83.4	0.6	-0.2
SAB	81.8	1.6	82.0	0.6	-0.2
AVERAGE	82.5	1.3	82.8	0.6	-0.3

The increased spread in the data does have an influence when using statistical tests to compare mean values. Since

the standard deviation is artificially high due to the assumed slope, statistical tests may incorrectly indicate that the differences between mean values are not significant.

Since the average values of L_A' are relatively insensitive to variations in the assumed slope, for consistency all of the data presented in this report have been normalized using the factor of 30. To allow the performance of more detailed analyses or other types of analyses, the A-weighted levels from all of the Phase I, II, and III tests are tabulated in Appendix G.

5. ROUGHNESS MEASUREMENT RESULTS

5.1 MEASUREMENT PROCEDURE AND DATA

The mechanisms generating wheel/rail noise are commonly divided into three very general categories - squeal created on short radius curves, impact due to discontinuities such as rail joints and wheel flats, and roar noise. Roar noise is the continuous broadband noise created by the small scale roughness of the wheel tread and rail head. In the study of the mechanisms of wheel/rail noise*, analytical models of squeal, impact and roar noise were developed. In its simplest form the model developed for the roar noise is:

$$L_p = L_v + K + 20\,log\,H(\lambda)$$

where L_p is the 1/3 octave band sound pressure level; K is a constant that depends on a number of variables including distance from the track, radiation efficiency, track and wheel dimensions, and wheel and rail impedance; and L_v is the combined 1/3 octave roughness velocity spectrum of the wheel and the rail at the train speed. The factor $H(\lambda)$ represents the "filter characteristics" of the contact area between the wheel and rail. According to the analytical study, the finite contact area acts to filter the short wavelength roughness. Since the contact area is not a function of speed,

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*Paul J. Remington, et al., "Wheel/Rail Noise and Vibration, Volume 1: Mechanics of Wheel/Rail Noise Generation", DOT Report No. UMTA-MA-06-0025-75-10, May 1975 (PB 244 514).

the filter characteristics must be expressed as a function of wavelength (λ) rather than frequency.

According to the model of roar noise, reducing the roughness will reduce the noise radiated from the wheels and rails.

This study was set up to include periodic measurements of both the wheel and rail roughness. As originally conceived, the same instrumentation developed in the previous study was to be used. Unfortunately, after the project began it was discovered that the existing rail profilometer was not complete and in useable form so an alternative course was taken of developing a new piece of equipment outside of the existing contract. Due to unexpected difficulties, the rail roughness device did not prove to be operational on the SEPTA rails. However, the wheel roughness measurement device did perform as expected and wheel roughness measurements were accomplished during the Phase I and II tests, as planned. Unfortunately, no wheel roughness tests were possible during the Phase III tests because the roughness apparatus was lost during storage in the SEPTA shop.

The basic arrangement used for the measurement and analysis of the wheel roughness is shown in Figure 5-1. The car wheel is turned at 20RPM via a small variable speed electric motor and belt, while the tungsten carbide slider shoe is which the accelerometer is mounted is pressed against the tread of the rotating wheel at four-to-six equally spaced distances from the flange. The probe or slider shoe acceleration is recorded on a magnetic tape recorder using a frequency modulated system with flat frequency response from 1 Hz to 1000 Hz.

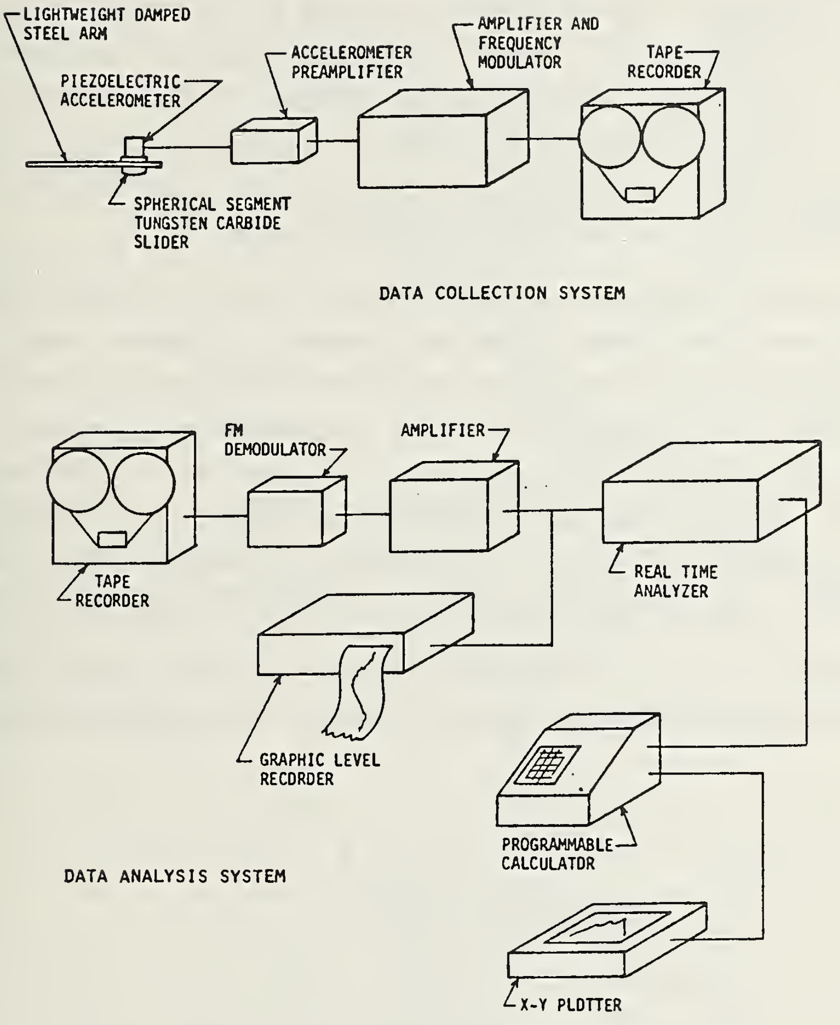

FIGURE 5-1. SCHEMATIC DIAGRAM OF APPARATUS FOR COLLECTION AND ANALYSIS OF WHEEL ROUGHNESS DATA

Since the model of roar noise predicts that noise level is directly proportional to the velocity spectrum of the combined wheel and rail roughness, roughness spectra are presented in this report in terms of the velocity level at a speed of 54 km/hr. The tangential speed of the wheel running surface at 20 rpm is 2.7 km/hr. Using a speed of 54 km/hr provides a 20:1 speed scaling which allows direct frequency scaling of the 1/3 octave band data using the normal 1/3 octave band center frequencies. Also 54 km/hr is near the median test speed for the noise measurements.

A number of wheel roughness tests have been performed. One of the problems associated with wheel roughness tests is that roughness is not constant over the tread surface of the wheel. There are generally several very distinct bands, each with noticeably different wear patterns and different roughness. On new wheels or wheels that have been recently trued, wear patterns have not had time to develop, and the tread surface has relatively uniform roughness across the width.

Figure 5-2 is a sketch of a typical wear pattern found on SEPTA wheels that have been in service for several months.

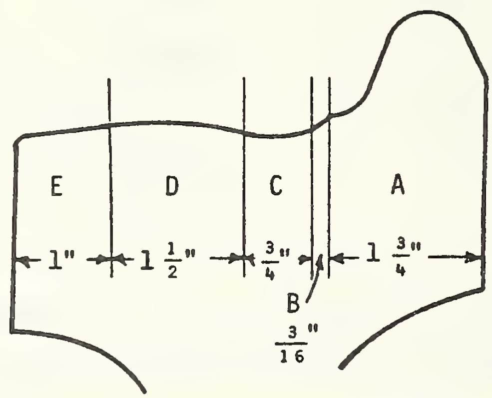

Figure 5-2 Typical Wear Pattern for SEPTA Wheels (not to scale)

Zone A does not appear to normally ride on the track surface. The surface is relatively rough with tooling marks and the contour is smooth. Zone B is a sharply angled ramp - apparently due to the brake shoe. Zone C is a very smooth band with very few pits and no spalling. It is possible that it is also created by the brake shoes and is not related to noise radiation, although it may be due to the flange riding against the rail on sharp curves. Zone D appears to be the primary running surface; it is quite rough with many pitted and spalling sections. It is somewhat surprising that this Zone is convex outward while Zone C is concave. Zone E does not appear to normally ride on the rail and except for corrosion remains essentially the same as when it was last machined.

To attempt to accurately represent the roughness of the entire wheel tread, the procedure adopted was to measure roughness along circumferential tracks spaced at 1/2" intervals on each of the wheels tested. Depending on the wear pattern - four to six samples were taken for each wheel. A single spectrum representing the average roughness for each wheel was then developed using the energy average of the individual samples. The data were further reduced by energy averaging the samples for the various test wheels on each test train. This provided an average spectrum to characterize each wheel type. It was originally thought that the average spectra could be reduced to single numbers analogous to the A-weighted level for noise data. At this point the single number descriptor of roughness has not been developed.

5.2 DISCUSSION OF RESULTS

Figure 5-3 illustrates the average 1/3 octave band roughness velocity spectra at 54 km/hr for each of the various

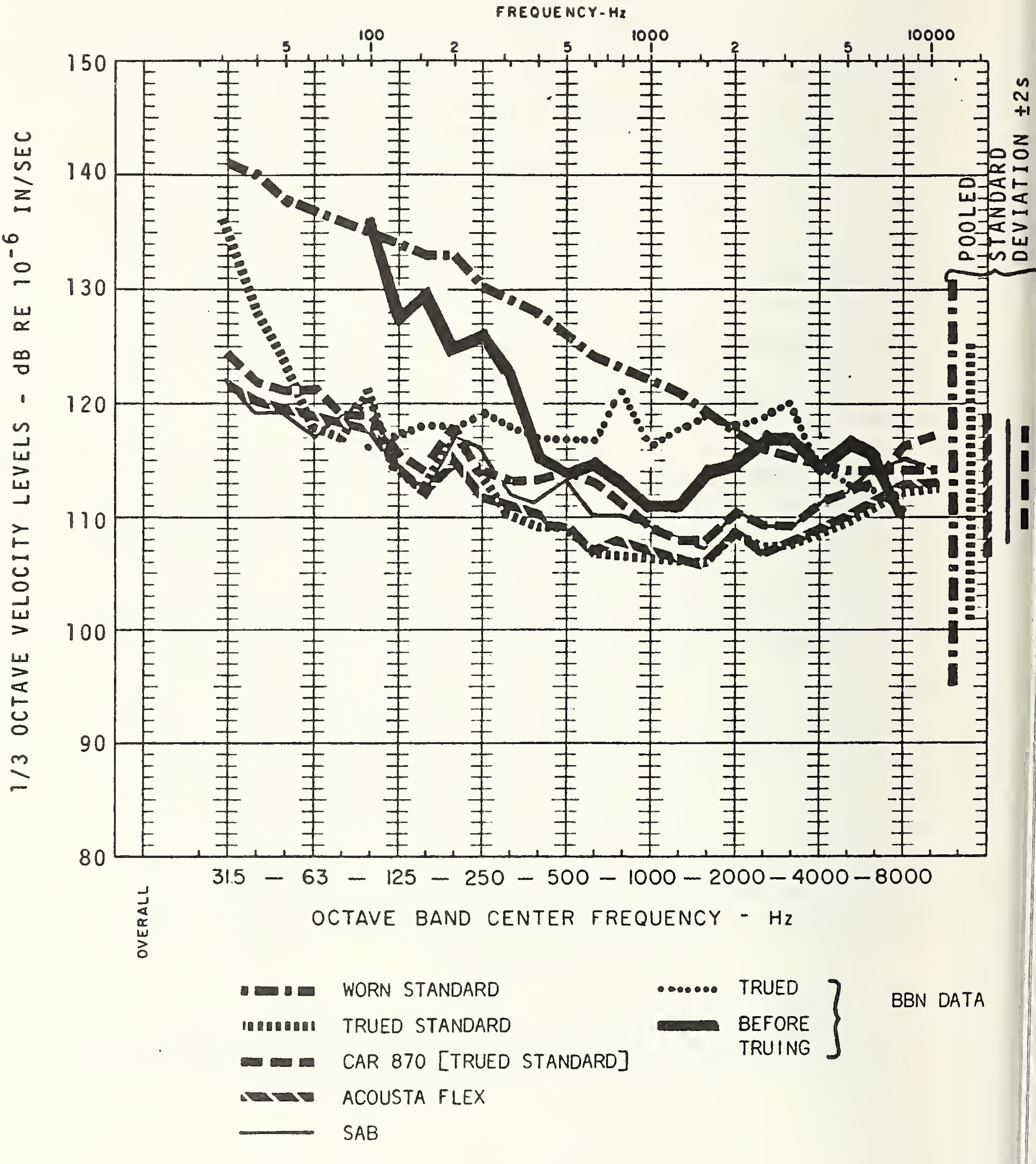

FIGURE 5-3. AVERAGE VELOCITY LEVELS FOR WHEEL ROUGHNESS - DATA NORMALIZED TO 54 KM/HR TRAIN SPEED

wheel categories. Roughness velocity spectra are presented as a function of frequency instead of wave number, since this has more intuitive significance and is easily scaled to other speeds. The actual measurements were taken with the wheels turning at 20 RPM, equivalent to 2.7 km/hr (1.7 mph). To speed scale the data, the frequency is multiplied by 20 - representing a shift of thirteen 1/3 octaves. The scaling factor of 20 was chosen since it represents an integral number of 1/3 octaves and corresponds to a speed in the mid-range of the test speeds. The exact test speed was determined by equipment limitations.

In speed scaling the roughness data it is necessary to account for the changes in velocity and acceleration levels with changes in train speed. The spectrum of the displacement level, L_D, is invariant with train speed, and is related to the measured 1/3 octave acceleration level, L_{A_1}, by:

$$L_D(\lambda) = L_{A_1} - 100 - 40 \log f_1$$

$$\lambda = \frac{V_1}{f_1}$$

where λ is the wavelength of the roughness, V_1 is the linear velocity at which the measurement is taken, and f_1 is the 1/3 octave center frequency. The displacement level is in dB re 10^{-6} inches and the acceleration level is dB re 10^{-6} g. To convert to the roughness velocity for a train speed of V_2, the relationship is:

$$L_{V_2} = L_D(\lambda) + 136 + 20 \log f_2$$

or

$$L_{V_2} = L_{A_1} + 36 + 20 \log \frac{f_2}{f_1^{\ 2}}$$

where f_2 is the 1/3 octave band center frequency. The velocity level, L_V, is in dB re 1 x 10^{-6} inches/second.

In the theory developed by the previous study*, the noise level in each 1/3 octave band is directly proportional to L_V, the roughness velocity.

Figure 5-4 shows the actual acceleration levels measured on one of the worn standard wheels and one of the trued standard wheels. The measurements were taken on circumferential tracks spaced at 1/2 in. intervals along the tread from the flange fillet. As is evident, the roughness spectra for the worn wheels are strongly dependent on the location at which the measurement is made. A 1/2 in. change in position can result in a large difference in the roughness spectrum. In specific 1/3 octave bands there is as much as a 30 dB spread between the highest and lowest roughness levels measured on a single worn standard wheel. The spectra for the various measurements with the new standard wheels show less dependence on the probe location on the tread surface - 10 dB being a typical range in each 1/3 octave band on the new standard wheels.

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*Paul J. Remington, et al., "Wheel/Rail Noise and Vibration, Volume 1: Mechanics of Wheel/Rail Noise Generation", DOT Report No. UMTA-MA-06-0025-75-10, May 1975 (PB 244 514).

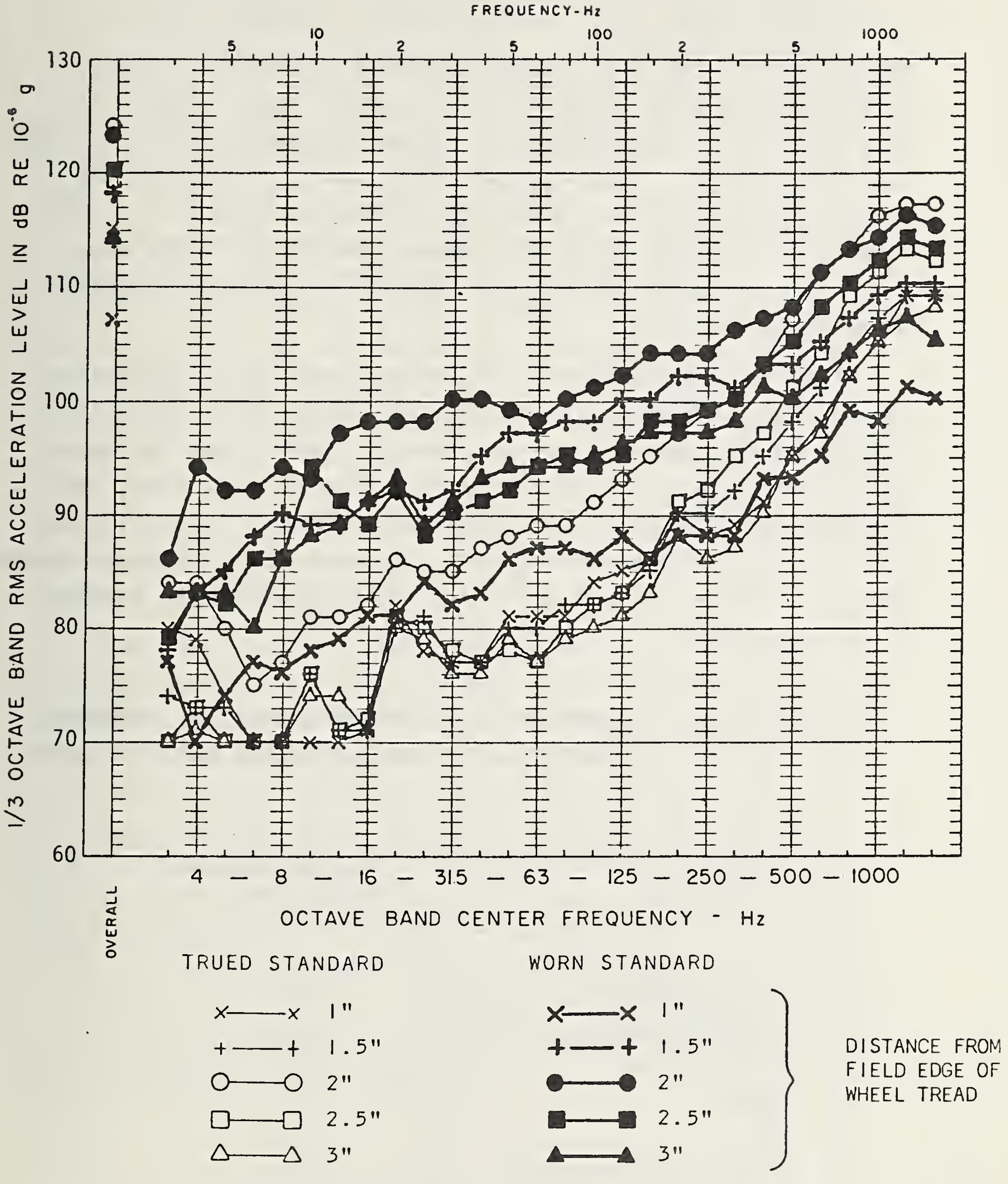

FIGURE 5-4 TYPICAL RANGE OF ROUGHNESS ACCELERATION SPECTRA MEASURED ON WORN STANDARD AND TRUED STANDARD WHEELS

Figure 5-3 illustrates the average velocity spectrum of the various wheel sets. For each type of wheel, all of the measurements have been energy averaged to develop a roughness spectrum characteristic of the wheel type. When calculating the energy average, a pooled standard deviation was also calculated. This standard deviation is based on the arithmetic averages for each 1/3 octave level and is a measure of the spread of the roughness spectra for each wheel set. The standard formula was used to estimate the pooled standard deviation.

When random data have a Gaussian (normal) distribution approximately 95 percent of the data points are within two standard deviations of the true mean. Hence, one can expect the range of the data points to be about plus or minus two standard deviations. This range is shown in Figure 5-3 for each wheel type. As is evident, the range for the worn standard wheels is about ± 18 dB while the newer wheels have a range of about ± 7 dB.

TABLE 5-1. SUMMARY OF POOLED ESTIMATES OF STANDARD DEVIATION OF ROUGHNESS FOR EACH WHEEL TYPE

Wheel Type	Pooled Standard Deviation - dB
Worn Standard	8.9
Trued Standard	6.4
Acousta Flex	3.2
Bochum	--
SAB	3.3
Freshly Trued (870)	2.2

When the measurements were taken, the wheels on the worn standard wheel train had run approximately 50,000 miles,

the new standard wheel train about 5,000 miles, the Acousta Flex and Bochum wheel trains less than 100 miles, and the SAB wheel train about 5,000 miles. The wheels on Car 870 had not been run since being trued. The primary factor indicated by the standard deviation estimates is that the wheel roughness becomes considerable less uniform as the wheels wear - confirming the visual inspection of the wheels.

The velocity spectra shown in Figure 5-3 show that the roughness of all of the relatively new or recently trued wheels are very closely grouped, while over most of the frequency range the worn wheels are significantly rougher than all other wheel types. Below 1000 Hz, the roughness for the worn wheels is 10 to 15 dB higher than the roughness for the other wheels. Also shown in Figure 5-3 are wheel roughness data from the earlier study for a wheel before and after wheel truing. These curves are generally between the spectrum for the worn wheels and the group of spectra for new and recently trued wheels.

Assuming that the wheels have greater amplitudes of roughness than the rail, the roar noise theory implies that the noise level with the worn wheels should be significantly higher than with the newer wheels. The fact that the sound level data indicated there was no large difference between the wayside noise levels with the worn and new wheels may indicate that the rail roughness dominates. However, grinding the rail did not substantially change the noise level. Another possibility is that the noise from the propulsion system limited or masked the observable reduction in wheel-rail noise. Hence, it is possible that the level of wheel-rail noise was substantially reduced but the propulsion equipment noise masked the reduction.

Figure 5-3 includes wheel/rail roughness data from other sources scaled to the same speed as the present data. The data included are for a wheel both before and after truing. It is evident that these data show the same general form and levels as the measurements performed in these tests, thus indicating that the two measures of wheel roughness do give similar results. Another possible interpretation of the lack of correlation between the noise measurements and the roughness measurements could be that the variations in local hardness of the rail and wheel or the crystalline structure of the steel may be of greater importance than the unloaded surface roughness in determining the level of roar noise produced by the wheel rolling on the rail.

6. COST DATA

6.1 SURVEYS OF TRANSIT SYSTEMS AND MANUFACTURERS

North American Rapid Transit Authorities were solicited concerning their past experience with noise abatement techniques and to determine their capital, operating, and maintenance expenditures for wheel truing and rail grinding programs.

Wheel and equipment manufacturers were also contacted to determine capital and life-cycle costs and the life expectancy for resilient and standard steel wheels and the equipment used in the wheel truing and rail grinding process.

Transit system information was obtained by a combination of detailed questionnaires and on-site interviews with engineering, operating, and maintenance personnel. The following systems participated in the survey:

- Bay Area Rapid Transit (BART)
- Chicago Transit Authority (CTA)
- Greater Cleveland Regional Transit Authority (GCRTA)
- Massachusetts Bay Transit Authority (MBTA)
- New York City Transit Authority (NYCTA)
- Port Authority Transit Corporation (PATCO)
- Port Authority Trans Hudson Corporation (PATH)
- Southeastern Pennsylvania Transportation Authority (SEPTA)
- Toronto Transit Commission (TTC)
- Washington Metropolitan Area Transit Authority (WMATA)

Information was obtained from manufacturers by correspondence and telephone.

Tables 6-1 through 6-7 reflect the key data collected from the manufacturers and the transit authorities. Descriptions of the transit systems, their experiences with resilient wheels, damped wheels, wheel truing, and rail grinding, and detailed descriptions of the methods, procedures, manpower requirements, and costs for performing wheel changing, wheel truing, and rail grinding are presented in Appendix E.

TABLE 6-1. WHEEL DATA FURNISHED BY MANUFACTURERS
(ALL WHEELS - - 28-INCH DIAMETER)

MANUFACTURER: WHEEL:	SAB TYPE 329	PENN MACHINE CO. PENN CUSHION Bochum 54	STANDARD STEEL ACOUSTA FLEX	STANDARD STEEL SOLID STEEL
COST (1976$):				
Complete wheel (ea.) (f.o.b. Phila.)	1,225	823.50	990	425
Tire (each)	390	245.30	360	-
Inserts (per wheel)	170	134.35	Non-Removable	-
Special Equipment	0 (A)	40,000 (C)	3,500 (G)	-
WEIGHT (lbs):				
Complete wheel	572	529	430	600
Tire only	248	310	290	-
LIFE:				
Wheel center	30 yrs.±	30 yrs.±	30 yrs.±	-
Tire (miles x 1000)	500-620	(D)	approx. 480 per 1" wear	approx. 480 per 1" wear
Insert (miles x 1000)	500-1,250	same as tire	same as tire	-
RENEW TIRE:				
Man Hours per car	4 (B)	12 (C)	16 (H)	-
RENEW INSERT:				
Man Hours per car	4 (B)	(E)	-	-
INSPECTION:				
Frequency	twice/year	No standard	No standard	No standard
Man Hours per car	5-10 minutes	5 minutes (F)	Not available	Not available

NOTES: TABLE 6-1.

Data indicated by a dash (-) is not applicable.

(A) Wheel type 329 used in this study is an all bolted wheel with monoblock tire. SAB also makes a similar resilient wheel with a heat shrink fit tire which would require equipment similar to that used with Acousta Flex wheel for tire renewal.

(B) SAB rubber inserts must be removed to renew monoblock tire and tire must be removed to renew inserts. Same four hours applies to performance of either or both functions. Renewal is performed on the car with the car jacked up for access to the wheels.

(C) Special Equipment Cost is for a special press to press tires off and onto wheel center. This press allows wheels to remain on axle once axle is removed from truck.

(D) Manufacturer states that tire life is averaging 40 percent more than solid steel wheels at properties where installed.

(E) Insert is destroyed when tire is removed. Renew both tire and inserts in same operation.

(F) Assumes car in shop over a pit to provide ready access to backs of wheels.

(G) Special Equipment Cost is for a gas burner ring, water spray ring, and handling hooks for renewal of heat shrink fit tire.

(H) Time to cut off old tire and heat shrink fit new tire given wheel removed from axle.

It was planned that the life expectancy of each type of wheel could be determined during the test program by taking wheel measurements at various intervals and by recording the mileage shown on the hubodometers. Unfortunately, all resilient wheels were removed from the program prior to any significant wear being observed.

Figure 6-2 contains SEPTA's estimated time and costs for the inspection and replacement of the various wheels. With the exception of the solid steel wheels, the estimates are based upon SEPTA's experience during the test program. The costs reflect SEPTA labor rates.

TABLE 6-2. SEPTA ESTIMATES FOR INSPECTION AND REPLACEMENT OF WHEELS

MANUFACTURER:	SAB	PENN MACHINE CO.	STANDARD STEEL	STANDARD STEEL
WHEEL:	TYPE 329	PENN CUSHION Bochum 54	ACOUSTA FLEX	SOLID STEEL
INSPECTION:				
Man-hr/car	64 minutes	32 minutes	32 minutes	16 minutes
Cost (1977 $)	13.07	6.53	6.53	3.27
RENEW TIRE (A):				
Man-hr/car	16 (B)	62	108	92 (C)
Cost (1977 $)	155.12	618.96	1,058.08	898.40

NOTES:

(A) Tire renewal costs are based upon SEPTA pay rates and maintenance techniques and manufacturers tire renewal procedure.

(B) SEPTA has no provision for safely jacking car by trucks for this wheel work; consequently, they would use lift, remove third shoe and rig safety chain from car body to truck. This procedure would consume three hours for two overhaulers in setting up and lifting car, another three hours for two men in lowering/restoring car, plus actual tire renewal. Given a different jacking arrangement, the six hours in raising and lowering the car could be reduced to less than one hour.

(C) No tires to renew. Cost/Labor is to change out a car set of eight solid steel wheels using SEPTA's Market Frankford Line procedures. These labor costs are also applicable to changing out Acousta Flex and Bochum wheels, but SAB wheels require an additional five minutes to install locking devices between the rim and wheel center during pressing operations. Thus, since three men are employed at SEPTA during pressing operations, an additional 0.25 man hours, costing $2.50, per wheel is incurred when pressing a SAB wheel off or onto an axle.

TABLE 6-3. WHEEL DATA FURNISHED BY TRANSIT SYSTEMS

SYSTEM	BART	CTA	GCRTA	MBTA	NYCTA	PATCO	PATH	SEPTA MKT.-FRANK.	SEPTA BROAD ST.	TTC	WMATA
Number of cars	450	1094	117	333	6674	75	298	257	156	498	
Wheel Diameter (in.)	30	28&26	28	28&26	34	28	28	28	28	28&30	28
Annual Miles/car		45,000	20,000	not avail.	50,000	53,000	a. 18,000 (3) b. 35,000	36,000	36,000	a. 55,000 (5) b. 75,000	not avail.
WHEEL LIFE:											
a. miles x 1000	800	1,000	a. 200-250 (2) b. 450-500	300	300	240-300	a. 350 (3) b. 150-250	200-250	400-450		not avail.
b. approx. yrs. (1)		22	a. 10-12.5 (2) b. 22.5-25	not avail.	4.8	4.5-6.6	a. 19.4 (3) b. 4.3-7.14	5.5-6.9	11.1-12.5		not avail.
Condemn at		2½"diameter wear	2"diameter wear	2½"&2" diameter wear	2"diameter wear	2" diam. wear	2" diam. wear	2"diameter wear	2"dia. (4) wear	3" diam. wear	
INSPECT WHEELS AT:											
Mile intervals		6,000	8,000	not avail.	7,500	12,500	every 50 days	12,000	4,000	13,000	(6)
TOTAL LABOR/COST PER CAR TO CHANGE (8) WHEELS:											
a. Elapsed time (hr)		46.11	34.18	54		46	34.7	58	53.6		34.68
b. Man hours		62.47	58.36	91.5		111.04	99.1	92	103.8		62.68
c. Cost of Labor ($)*		756.22	622.12	1213.07		965.64	1066.92	898.40	1009.04		671.36

*Costs reflect 1977 dollars.

NOTES: TABLE 6-3

(1) Average wheel life in years based on average annual miles/car and system estimated wheel life in miles.

(2) a. = Pullman Standard cars; b. = St. Louis cars.

(3) a. = K Series cars; b. = PA Series cars.

(4) AAR tape used, wheel tape at 240 ± when new, 160 at condemning limit.

(5) a. = 30-inch wheel cars; b = 28-inch wheel cars.

(6) Anticipate 10,000-mile interval will be established, currently wheels inspected on monthly basis.

TABLE 6-4. WHEEL TRUING DATA FURNISHED BY MANUFACTURERS

MANUFACTURER	MODEL	1977 COST ($)	CUTTING TOOL USAGE/COST	ANNUAL MAINTENANCE	REMARKS
FARREL	50" Hydraulic Trace Control	500,000	1 per 2-3 wheels/ $7 to $12 each	10-15 gal. - lube oil 50-70 gal. - hydraulic oil	above (B) floor lathes
	Programmed Lathe	700,000	N.A.	N.A.	
SIMMONS	42" Hydraulic Profiling	335,000	N.A.	N.A.	
HEGENSCHEIDT	104 & 105	500,000 (A)	$55 per 10-wheel sets	2-3% down time including preventive maintenance	underfloor (C) lathes
	106	480,000- (A) 600,000	$55 per 10-wheel sets	2-3% down time including preventive maintenance	
STANRAY	Standard unit with car puller & chip disposal	370,000 (A)	1.5 per wheel set at $1.50 each	$190 - oils	underfloor (C) milling machine

NOTES:

(A) Cost includes installation, does not include construction of pit. Stanray estimates $40,000 for typical pit construction dependent upon soil conditions.

(B) Above floor lathes require removal of wheels from car. Typically, wheels trued on axle removed from truck.

(C) Under floor lathe and milling machine do not require wheel to be removed from car as car is driven over machine. Removed trucks or axle sets may be trued.

N.A. Not available

TABLE 6-5. WHEEL TRUING DATA FURNISHED BY TRANSIT SYSTEMS

SYSTEMS	ABOVE FLOOR LATHES					UNDERFLOOR MILLING MACHINES			UNDERFLOOR LATHES			
	CTA	MBTA EVERETT SHOP	PATH	PATCO	SEPTA BROAD ST.	MBTA (D)	NYCTA (E)	SEPTA MARKET-FRANKFORD	BART	GORTA	TTC	WMATA
MANUFACTURER	Sellers	Niles	Farrel	Sellers	Baldwin-Lima-Hamilton	Stanray	Stanray	Stanray	Farrel	Hegenscheidt 104		104
Cost ($) (A)	N.A.	80,000	187,000	20,000	N.A.	265,000 (F)				400,000		226,000
Year (B)	N.A.	19[illegible]5 (used)	1974 (1954)	1970 (1941)	1952	1973	1957	1972		1976		1972
Number of revenue cars	1094	(G)	298	75		(G)	6674		450	117	498	(P)
Annual miles/car (miles x 1,000)	45	N.A.	a. 18 (I) b. 35	53	36	N.A.	50	36		20	a. 55 (O) b. 75	(P)
Wheel life (miles x 1,000)	1000	300	a. 350 (I) b. 150-250	240-300	400-450	300	300	200-250		(M) a. 200-250 b. 450-500		(P)
Miles between truing (x 1,000)	300-400	N.A.	a. 88 (I) b. 38-62	55-70	100	N.A.		60		75		(P)
Axle sets trued/8-hour shift	3-5	2	6	4	2	4		4	2	4	4	4
Axle sets trued/year	830	615	300	140	150	N.A.		456		800		(P)
TRUING LABOR/COST PER CAR SET OF 8 WHEELS:												
Elapsed time (hr.)	24.55	42	13.7	16	42	8		8.5		8		9.33
Man-Hours (C)	45.75	73.5	38.1	36	80	8		8.5		8.5		14.67
Labor Cost ($)	545.14	849.35	391.68	310.30	774.84	100.56		84.64		96.11		157.24
ANNUAL COSTS ($) - ONE MACHINE:												
Cutting tools	6450 (H)	1876	476	1741	1000	N.A.				2600		(P)
Maintenance	N.A.	N.A.	127 (J)	2000 (K)	N.A.	N.A.		2775 (L)		2600 (N)		(P)

N.A. = Not available. Truing Labor/Costs reflect 1977 dollars.

NOTES: TABLE 6.5

(A) Cost of machine reflects purchase price and is exclusive of installation and pit construction costs.

(B) Year in parentheses is original construction date of equipment.

(C) Truing time typically includes daily servicing of machine.

(D) One machine each at Cabot and Wellington Car Houses.

(E) Two machines at Concourse Yard and one at Coney Island Yard.

(F) Includes $25,000 for car progression system.

(G) MBTA operates 333 revenue cars. Most of Red Line's 164 cars are trued at Cabot Car House, and most of Orange Line's 100 cars are trued at Wellington Car House, but Everett Shop continues to true wheels from those two lines in addition to Blue Line's 69 cars and Green Line's light rail cars.

(H) An additional $3,240 is spent annually on grinder wheels. CTA employs a wheel grinder in conjunction with wheel lathe to reprofile wheels.

(I) a. = K series cars; b. = PA series cars.

(J) $127 is approximate cost of consumables other than cutting tools.

(K) Major overhaul scheduled every two years at approximate cost of $4,000 for labor and material.

(L) One man day is spent in general servicing and clean up after every fourth car is trued, plus $500 for non-tool consumables. Additionally, manufacturer inspects machine approximately every 18 months.

(M) a. = Pullman Standard cars; b. = St. Louis cars.

(N) One man day is spent in general servicing and clean up after every fourth car is trued; plus something less than $100 for non-tool consumables.

(O) a. = 30-inch wheel cars; b. = 28-inch wheel cars.

(P) System has not been completed; valid data not available.

TABLE 6-6. RAIL GRINDING DATA FURNISHED BY MANUFACTURERS

MANUFACTURER	LORAM	SPENO		
UNIT	24 Stone-Rail Grinder	24 Stone-Rail Grinder Trains		
		Mobile Grinding Trains	Similar to Bart's	Similar to SEPTA's
1977 COST ($)	870,000	Contract services only	500,000(A)	550,000(B)
GRINDING SPEED (MPH)	0-3 (2 optimum)	1.2 - 2.2	2 opt.	2 opt.
RAIL SURFACE REMOVED PER PASS (INCHES)	.003 - .005	.0015	.0015	.0015
CONTRACT SERVICES *			REMARKS	
HOURLY RENTAL ($)	155	154	For Both: 10-hr day 6 day minimum	
LABOR COST	$25 per diem-2 men	incl. in rental-3 men	-	
MATERIAL COST	fuel oil & stones	incl. in rental	Loram estimates 24 stones per 10-hr at $25 each	
FREIGHT ($)	not available	2805	-	
6-DAY CONTRACT COST ($)	12,650 (C)	12,085	-	
RESTRICTIONS:	Basically a railroad unit. Transit system clearances must be addressed individually.	10-inch stones obstructed on sharp curves if restraining rail within 5" of running rail center line.	Both units: Restricted to standard 4' 8½" gauge. Loram unit: also has 10" stones.	

Notes:

(A) BART grinder train employs yard locomotive not included in cost. Diesel generator and air compressor on another car.

(B) SEPTA grinder train employs diesel locomotive with diesel generator and air compressor on locomotive. Included in cost.

(C) Does not include shipping, fuel, or oil. Estimates 8.5 hours per day of actual grinding and consumption of 122 stones in 6 days.

* Costs reflect 1977 dollars

TABLE 6-1. RAIL GRINDING DATA FURNISHED BY TRANSIT SYSTEMS

SYSTEM	BART	CTA	NYCTA	SEPTA	PATCO	TTC
MANUFACTURER	Speno	CTA (A)	Speno	Speno	Contract (B)	TTC(A)
PURCHASE COST (year purchased $)		not avail.	1,000,000	250,000	-	
YEAR PURCHASED		1972/1977 (C)	1970	1972	-	
NUMBER OF GRINDING STONES OR BRICKS (A)	24	14/28	96	24	24	48
GRINDING SPEED (MPH)		20 to 40	1.25	1.5	1	
RAIL SURFACE REMOVED PER PASS (INCH)		not avail.	.010	.0015	.0015	
MILES GROUND/YEAR		80/160	350	80	28.4 (B)	
AVERAGE NUMBER OF PASSES		225/112	3	10	2	
ANNUAL LABOR COSTS (1977 $)						
OPERATING	244/day	89,799	355,000	39,360	-0-	
SUPPORT (D)	37/day	-0-	125,000	20,940	910	
MAINTENANCE		not avail.		12,600	-0-	
ANNUAL MATERIAL COSTS (1977 $)						
CONSUMABLES	125/day	12,000/not avail.	19,500	6,466	-0-	
MAINTENANCE				10,650	-0-	

NOTES:

(A) CTA and TTC employ abrasive bricks pressed against rail for grinding, all others listed here employ rotating grinding stones.

(B) PATCO contracts grinding services for entire system every two years. All data is on a bi-annual basis and on SPENO unit typically contracted.

(C) CTA modified its 1972 - 14-brick grinder car to a 28-brick grinder in 1977.

(D) Support refers to non-operating and non maintenance labor required during grinding operations such as personnel for single tracking not already stationed for normal revenue operations and liaison personnel during contracted services.

6.2 COST ANALYSIS

The information obtained from the surveys and interviews conducted with the transit systems, material suppliers, equipment suppliers, and the data developed by SEPTA during the first two phases of the test program can be analyzed by life-cycle cost techniques to determine the total costs associated with resilient wheels, wheel truing, and rail grinding. The total costs for each technique of noise reduction are comprised of initial costs, maintenance costs and replacement costs, and are dependent upon the service life of materials and equipment and maintenance and inspection cycles.

6.2.1 Wheels

As shown in Table 6-1, the purchase cost per wheel varies considerably, with solid steel wheels being the least expensive at $425 per wheel, followed by the Bochum wheel at $823.50, the Acousta Flex wheel at $990, and the SAB wheel at $1,225. Each of the resilient wheels is constructed to allow the replacement of the tire, thereby reducing replacement costs considerably when compared to the solid steel wheel which must be replaced in its entirety when the tire reaches its condemning limit.

Tire life for the solid steel, Acousta Flex, and SAB wheels is similar according to the manufacturers' literature; however, the manufacturer of Bochum wheels claims that the Bochum tire averages a 40 percent longer tire life than that achieved by solid steel wheels. Wheel and tire lives have a great effect on economic evaluations as present value calculations use life cycles as a basic input.

One of the goals of the testing program was to determine the service life of the various types of wheels by measuring the size of the wheels at various intervals throughout the service testing period and by keeping accurate records of mileage traveled by the test vehicles. Unfortunately, all resilient wheels were removed from the test cars prior to the

accrual of sufficient mileage to allow a computation of expected tire life to be made.

Other factors contributing to the life cycle cost of the wheels are the costs related to replacement and routine inspection. Concerning replacement, the manufacturers' estimate of the effort required to replace tires is far below the effort estimated by SEPTA, varying by as much as 92 man hours per car set in the case of Acousta Flex wheels. SEPTA's estimates are based upon very limited experience with resilient wheels and could be influenced by their shop personnel's lack of confidence in the wheels. On the other hand, the manufacturers' figures are probably based upon optimized situations.

Similarly, SEPTA's wheels inspection cost estimates are also considerably above those of the manufacturers. SEPTA allows 16 minutes for the inspection of a car set of solid steel wheels. Their estimates, based on the complexity of construction of the resilient wheels, are that 32 minutes would be required for the inspection of a car set of Acousta Flex or Bochum wheels and 64 minutes for the inspection of a car set of SAB wheels. It is logical that the inspection of the resilient wheels requires additional time; however, it seems likely that the differential in time will decrease as the inspection personnel gain confidence in the performance of the resilient wheels. The SAB and Bochum wheel manufacturers estimated that the wheel inspections would be 5-10 minutes per car, a figure considerably less than SEPTA spends inspecting solid steel wheels.

The sensitivity of these variances can be determined by applying the various values to the life-cycle cost equations and examining the answers calculated. The life-cycle cost equations for resilient and solid steel wheels are as follows:

Equation 1 - Resilient Wheels

$$PV = X_1 + \sum_{t=1}^{t=n} \frac{x_2(1+i_f)^t}{(1+i)^t} + \sum_{t=m+1}^{\substack{t=2m+1,3m+1,\\ \ldots \le n}} \frac{x_3(1+i_f)^{t-1}}{(1+i)^{t-1}} - \sum_{t=m}^{\substack{t=2m,3m,\\ \ldots \le n}} \frac{x_4(1+i_f)^t}{(1+i)^t} - \frac{x_5(1+i_f)^n}{(1+i)^n}$$

Where:

PV = present value of life cycle costs ($)

x_1^* = initial cost of resilient wheels ($)

x_2 = annual cost of inspecting resilient wheels ($)

x_3^{**} = cost of replacing portions of the resilient wheels (tires, inserts, etc.) ($)

x_4 = scrap value of replaced parts ($)

x_5 = scrap value of complete wheel at end of service life ($)

n = service life of wheel (years)

i = annual interest rate (decimal equivalent)

i_f = annual inflation rate (decimal equivalent)

m = service life of replacement parts (tires, inserts, etc.) (years)

* Initial cost includes purchase price + cost of installation + cost of any special equipment required for installation of resilient wheels

** Replacement costs include purchase price + cost of installation

Equation 2 - Solid Steel Wheels

$$PV = X_6 + \sum_{t=1}^{t=n} \frac{x_7(1+i_f)^t}{(1+i)^t} - \frac{x_8(1+i_f)^n}{(1+i)^n}$$

Where:

x_6^* = initial cost of solid steel wheels ($)

x_7 = annual cost of inspecting solid steel wheels ($)

x_8 = scrap value of wheel at end of service life ($)

* Initial cost includes purchase price + cost of installation

Each of the above equations calculates the present value, including an inflation factor, of the total costs expended over the life of the wheels. However, since the life cycles of the different wheels vary in length, the equations should be adjusted in order to allow a comparison to be made of the present value of the life-cycle costs over an identical period. To accomplish such a comparison, a residual value term must be considered.

$$RV = \frac{\dfrac{.75\ OC - VUL}{YUL - 1} \times RYUL}{(1+i)^{p}}$$

Where:

OC = original cost

VUL = scrap value

YUL = length of component life cycle

RYUL = remaining years of the life cycle

P = total years in period under consideration

Then, by summing all terms over a chosen period, p, the following generalized equations result:

<u>Equation 1A - Resilient Wheels:</u>

$$PV = \sum_{t=1}^{\substack{t=n+1,2n+1,\\ \ldots \le p}} \left[\frac{x_1 (1+i_f)^{t-1}}{(1+i)^{t-1}} + \sum_{L=m+1}^{\substack{L=2m+1,3m+1,\\ \ldots \le n}} \frac{x_3 (1+i_f)^{L+t-2}}{(1+i)^{L+t-2}} - \sum_{L=m}^{\substack{L=2m,3m,\\ \ldots \le n}} \frac{x_4 (1+i_f)^{L+t-1}}{(1+i)^{L+t-1}} \right]$$

$$+ \sum_{t=1}^{t=p} \frac{x_2 (1+i_f)^{t}}{(1+i)^{t}} - \sum_{t=n}^{\substack{t=2n,3n,\\ \ldots \le p}} \frac{x_5 (1+i_f)^{t}}{(1+i)^{t}} - \frac{\left[\dfrac{0.75x_1 - x_5}{n-1}\right](a-p)(1+i_f)^{p}}{(1+i)^{p}}$$

$$- \frac{\left[\dfrac{0.75x_3 - x_4}{m-1}\right]\left[b-(p-(a-n))\right](1+i_f)^{p}}{(1+i)^{p}}$$

Equation 2A - Solid Steel Wheels

$$PV = \sum_{t=1}^{\substack{t=n+1,2n+1,\\ \ldots \leq p}} \frac{x_6(1+i_f)^{t-1}}{(1+i)^{t-1}} + \sum_{t=1}^{t=p} \frac{x_7(1+i_f)^t}{(1+i)^t} - \sum_{t=n}^{\substack{t=2n,3n,\\ \ldots \leq p}} \frac{x_8(1+i_f)^t}{(1+i)^t}$$

$$- \frac{\left[\frac{0.75x_6 - x_8}{n-1}\right](a-p)(1+i_f)^p}{(1+i)^p}$$

Where:

a = a multiple of n just greater than or equal to p (i.e., $a=k_1 n \geq p > (k_1-1)n$, k_1 being an integer)

b = a multiple of m just greater than or equal to p-(a-n) (i.e., $b=k_2 m \geq p-(a-n) > (k_2-1)m$, k_2 being an integer)

As an example of the use of the life cycle equations, we will compare the present values (PV) of the life cycle costs for one car set of SAB and standard steel wheels using the manufacturers and SEPTA's data presented in Tables 6-1 and 6-2.

Equation 1 - Resilient Wheels

x_1 = (\$1,225 x 8) + \$918.40 = \$10,718

x_2 = \$13.07 x 3 = \$39

x_3 = (\$560 x 8) + \$155.12 = \$4,635

x_4 = 148 lbs x 8 x \$50/2,000 lbs = \$30

x_5 = 472 lbs x 8 x \$50/2,000 lbs = \$95

n = 28 years

i = 10 percent

i_f = 6 percent

m = 7 years

Development of values:

x_1 - purchase price as per SAB; installation cost as per SEPTA

x_2 - inspection cost as per SEPTA; inspection every 12,000 miles with average car traveling 36,000 miles per year

x_3 - tire and insert purchase price as per SAB; installation cost as per SEPTA

x_4 - assume scrap tire to weigh 148 lbs; scrap value to be \$50 per ton

x_5 - assume scrap wheel to weigh 472 lbs; scrap value to be \$50 per ton

n - manufacturers claimed wheel center life is approximately 30 years. Since tires are replaced at 7-year intervals, a wheel center life of 28 years is selected.

m - SEPTA achieving approximately 7 years life for wheels on Market Frankford Line (1"tread wear). SAB claims 1" allowable tread wear on tire and similar life expectancy for tire and inserts.

Applying the above values to Equation 1 gives:

$$PV = \$10,718 + \sum_{t=1}^{t=28} \frac{\$39(1.06)^t}{(1.1)^t} + \sum_{t=8}^{t=15,22} \frac{4635(1.06)^{t-1}}{(1.1)^{t-1}} - \sum_{t=7}^{t=14,21,28} \frac{30(1.06)^t}{(1.1)^t} - \frac{95(1.06)^{28}}{(1.1)^{28}}$$

PV = \$10,718 + 667 + 8,465 - 65 - 34

PV = \$19,751 for a 28-year service life for a car set of SAB wheels

<u>Equation 2 - Solid Steel Wheels</u>

x_6 = (\$425 x 8) + \$898.40 = \$4,298

x_7 = \$3.27 x 3 = \$10

x_8 = 500 lbs x 8 x \$50/2,000 lbs = \$100

n = 7 years; i = 10 percent; i_f = 6 percent

Development of values:

x_6 - purchase price as per Standard Steel; installation cost as per SEPTA

x_7 - inspection cost as per SEPTA; inspection every 12,000 miles with average car traveling 26,000 miles per year

x_8 - assume scrap wheel to weigh 500 lbs; scrap value to be \$50 per ton

n - SEPTA achieving approximately 7 years life for wheels on Market Frankford Line

Applying the above values to Equation 2 gives:

$$PV = 4{,}298 + \sum_{t=1}^{t=7} \frac{\$10(1.06)^t}{(1.1)^t} - \frac{100(1.06)^7}{(1.1)^7}$$

PV = 4,298 + 61 - 77

PV = 4,282 for a 7-year service life for a car set of solid steel wheels

Equations 1A and 2A should be used to compare these alternatives for an identical period of time. Assuming a period of 28 years, equations 1 and 1A yield the same results. Applying equation 2A for 28 years:

$$PV = \sum_{t=1}^{t=8,15,22} \frac{4{,}298(1.06)^{t-1}}{(1.1)^{t-1}} + \sum_{t=1}^{t=28} \frac{10(1.06)^t}{(1.1)^t} - \sum_{t=7}^{t=14,21,28} \frac{100(1.06)^t}{(1.1)^t}$$

$$- \frac{\frac{0.75(4{,}298)-100}{6}\ (28-28)(1.06)^{28}}{(1.1)^{28}}$$

PV = 12,148 + 171 - 219 - 0

PV = \$12,101

A comparison of the computed present values for the SAB and solid steel wheels shows the car set of SAB wheels to be 19,751 - 12,101 = \$7,650 or 63 percent higher than a car set of solid steel wheels using the manufacturers initial costs and SEPTA's installation and maintenance costs.

If the manufacturers' installation and maintenance costs are used, the present value of the total costs for a 28-year period are as follows:

Equation 1 - Resilient Wheels

x_1 = same

x_2 = 13.07 x 10/64 x 2 = \$4

x_3 = (\$560 x 8) + (155.12 x 4/16) = \$4,519

x_4 = same

x_5 = same

n = same

i = same

Development of values:

x_2 - manufacturer estimates 10 minutes per car required; SEPTA estimates 64 minutes; inspection required twice yearly.

x_3 - manufacturer estimates 4 man hours required for tire renewal; SEPTA estimates 16 man hours.

Applying the above values to equation 1 gives:

$$PV = 10{,}718 + \sum_{t=1}^{t=28} \frac{4(1.06)^t}{(1.1)^t} + \sum_{t=8}^{t=15,22} \frac{4{,}519(1.06)^{t-1}}{(1.1)^{t-1}} - \sum_{t=7}^{t=14,21,28} \frac{30(1.06)^t}{(1.1)^t} - \frac{95(1.06)^{28}}{(1.1)^{28}}$$

PV = 10,718 + 68 + 8,253 - 65 - 34

PV = \$18,930

The difference between the present value of the life-cycle costs using SEPTA installation and maintenance estimates as compared to the manufacturers installation and maintenance estimates is 19,751 - 18,930 = \$821 or 4.34 percent. From this it can be deduced that the life-cycle costs for resilient wheels are not sensitive to the variations in its estimates of the effort required to inspect and maintain the wheels, but are dependent only upon initial costs and the length of service life.

To analyze the effect of increased service life on the present value of life-cycle costs, we will assume that the life of a resilient wheel tire is 40 percent greater than the life of a solid steel wheel as claimed by Bochum. This will increase the service life of the tire and inserts to ten years and will allow the wheel center to be used for thirty years while the service life of the solid steel wheel remains at seven years. Applying these values to Equation 1 results in a present value of the life-cycle costs = $16,745 for a car set of SAB wheels.

Applying the solid steel wheel costs and service life to Equation 2A and calculating for a thirty-year period results in a present value of life-cycle costs = $12,774 for a car set of solid steel wheels.

The ratio of these present values is 1.2:1 as compared to 1.6:1 when the service life of the resilient tire is assumed to be the same as the service life of the solid steel wheel.

Therefore, it can be concluded that on the SEPTA Market Frankford line, a car set of SAB resilient wheels will cost between 1.2 and 1.6 times the amount of a car set of solid steel wheels over the life span of the SAB wheels.

If special equipment is required for the installation or renewal of resilient wheels, as is the case when using Bochum wheels, the life-cycle costs equation can examine the costs for a total car fleet of resilient wheels (or any portion desired) and then divide the present value (PV) by the number of cars selected to arrive at a cost per car set.

6.2.2 Wheel Truing

Wheel truing is a process whereby the original profile of a wheel is restored by cutting away a portion of the surface metal of a worn wheel in the area where the wheel contacts the rail. Wheel truing eliminates the additional noise caused by flat spots and other irregularities which may develop and, under circumstances where large irregularities have developed , improves ride quality, reduces impact forces on the rail thereby reducing track degradation and extends wheel life. Wheel truing is also used to maintain proper wheel flange depth in order that fouling of turnouts and frogs will not occur.

Wheel truing can be performed on above floor or underfloor lathes, or on underfloor milling machines. In general, above floor lathes require wheels to be removed from the trucks and axles, whereas underfloor lathes and milling machines allow the truing operation to be performed with the wheels remaining in place on the vehicle. Because of the variance in the level of effort required, the cost of truing wheels varies greatly from system to system. For example, as shown in Table 6-5, SEPTA expends $775 in labor costs to true a car set of wheels on an above floor lathe on their Broad Street line and only $85 to true a car set of wheels on an underfloor milling machine on the Market-Frankford line. The labor cost for truing wheels (see Table 6-5) ranges from $300 to $850 per car set on above floor lathes, and from $85 to $160 per car set on underfloor equipment at the various transit systems in North America.

Since the cost of above floor and underfloor wheel truing equipment is similar (Table 6-4), it is obvious that it is more economical to perform wheel truing operations on underfloor equipment provided that the shop facilities are designed to allow this operation.

The life-cycle costs equation for wheel truing is as follows:

Equation 3 - Wheel Truing

$$PV = x_9 + \sum_{t=1}^{t=n} \frac{x_{10}(1+i_f)^t}{(1+i)^t} - \frac{x_{11}(1+i_f)^n}{(1+i)^n}$$

Where:

PV = present value ($)

x_9 = initial cost of wheel truing equipment ($)

x_{10} = annual cost of wheel truing including labor costs and costs for maintaining and operating wheel truing equipment ($)

x_{11} = scrap value of equipment at end of service life

i = annual interest (decimal equivalent)

i_f = annual inflation (decimal equivalent)

n = service life of wheel truing equipment (years)

The calculation of the present value of wheel truing life-cycle costs and the comparison of these costs for the various transit properties is of little value for the following reasons:

- In a number of cases, equipment was purchased many years ago, often in used condition, and as such the initial costs are not comparable.
- The annual cost of wheel truing is dependent upon the number of vehicles in the fleet.
- The service life of wheel truing equipment is unknown and could vary depending upon usage.
- It is essential that each rapid transit system have the capability to perform wheel truing in order that wheels developing large flat spots or other major irregularities can be returned to normal and to maintain proper wheel flange size. Therefore, the question as to whether or not wheel truing should be performed is not applicable.

It does appear, however, that the area of interest lies in the amount of time and labor required to true a car set of wheels.

6.2.3. Rail Grinding

Rail grinding is a process by which a rail mounted vehicle, outfitted with grinding stones, travels along the track removing a certain amount of metal from the surface of the rail, ultimately returning the surface of the rail to its original contour. The purpose of rail grinding is to eliminate the additional noise caused by rail irregularities such as corrugations and to increase surface contact between the wheels and rail, thereby providing an improved medium for signal transmission and to increase rail and wheel life by reducing contact stresses.

Rail grinding trains can be purchased or rented, the decision apparently being based upon the incidence of track corrugations and the number of track miles requiring grinding. Several systems such as GCRTA, MBTA, and PATH do not employ rail grinding. Others such as BART, CTA, NYCTA, and SEPTA have their own rail grinding equipment. PATCO contracts for rail grinding on a biyearly basis.

The life-cycle cost equation for rail grinding is as follows:

Equation 4 - Rail Grinding

$$PV = x_{12} + \sum_{t=1}^{t=n} \frac{x_{13}(1+i_f)^t}{(1+i)^t} - \frac{x_{14}(1+i_f)^n}{(1+i)^n}$$

Where:

x_{12} = initial cost of rail grinding equipment ($)

x_{13} = annual cost of rail grinding ($)

x_{14} = scrap value of equipment at end of service life ($)

n = service life of rail grinding equipment

For those systems which contract for rail grinding services, terms x_{12} and x_{14} will be zero and term x_{13} will include the rental rates.

As the annual costs of rail grinding are dependent upon the number of miles ground, it appears that the most logical way of making a comparison between transit systems would be to divide the present value (PV) by the number of miles ground per year to arrive at a cost per mile.

7. CHANGES TO PROGRAM

The Experimental Design* and the Test and Evaluation Plan** Interim Reports set forth the subjects to be examined and the methods and procedures for performing the Urban Rail System Noise program. The program has generally proceeded according to plan, the major exception being the failure and removal from the test program of all three types of resilient wheels and SEPTA's decision not to allow the testing of the viscoelastic damped wheels. The scope of the program has been increased, however, to provide for the testing of ring damped wheels and to include additional documentation of propulsion system noise. Details of the program changes are as follows.

7.1 DELETION OF VISCOELASTIC DAMPED WHEELS

The test program was to have included a two-car set of viscoelastic damped wheels as provided by the Soundcoat Company. The drawings and specifications for the dampers had passed through normal channels and had been approved by SEPTA. However, upon receiving the dampers, SEPTA determined that they could not allow the dampers to be applied to the wheels and the wheels placed in revenue service as they were concerned about the ability of the dampers to remain in place under operating conditions. Because of this and the lack of a documented history of testing and safe operation, SEPTA refused to assume liability for operating with the wheels in service and insisted that the viscoelastic damped wheels be removed from the testing program.

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*Michael C. Holowaty, Hugh H. Saurenman, and Stanley M. Rosen, "In-Service Performance and Costs of Methods for Control of Urban Rail System Noise - Experimental Design," Report No. UMTA-MA-06-0025-76-4,May 1976. (NTIS No. PB 257-200).

**Hugh J. Saurenman and Michael C. Holowaty, "In-Service Performance and Costs of Methods of Control of Urban Rail System Noise - Test and Evaluation Plan," Report No. UMTA-MA-06-0025-77-10, April 1977. (NTIS No. PB 272-521).

7.2 PROBLEMS EXPERIENCED WITH RESILIENT WHEELS

The test program included one two-car set each of the following three types of resilient wheels:

- Bochum wheels supplied by the Penn Machine Company
- Acousta Flex wheels made by Standard Steel Company
- SAB wheels supplied by the American SAB Company, Inc.

During the course of the program, problems were experienced with each type of resilient wheel; and subsequently, all resilient wheels were removed from service. A description of the occurrences follows.

7.2.1 Bochum Wheels

Bochum wheels were installed on SEPTA cars 626 and 631 and on one axle of car 646. On December 10, 1976, the train in which cars 626 and 631 were operating reported to the shop as a slow train. Inspection of the train determined that Car 631 had hot wheels. The temperature labels indicated that Bochum wheel no. 64422 had experienced temperatures between 204°C and 232°C, wheel no. 64419 had experienced temperatures between 177°C and 204°C, and the remaining six wheels' labels indicated temperatures between 149°C and 177°C. The hubodometer indicated that the car had traveled 6,235 miles since the installation of the Bochum wheels. Two rubber blocks in wheel 64422 had experienced spalling damage and one block in wheel 64419 had split.

Investigation revealed that car 631 had lost dynamic braking thereby requiring the tread brakes to be applied at operating speed and to be used throughout the entire stopping operation instead of just during the final braking sequence. SEPTA cars do not have a dynamic brake failure indication system.

The temperatures experienced are below the test temperatures recorded in a laboratory test report prepared for the Paris Metro

entitled "Block Brake Tests on a Rubber Cushioned Single Ring Wheel Design Bochum 54". This test resulted in the manufacturer's original specification for a maximum allowable tire temperature of 275°C.

Wheels 64422 and 64419 were returned to the manufacturer, Fried Drupp Huttenwerke AG, Germany, for an in-depth analysis. Cars 626 and 631 were removed from revenue service pending the report of manufacturer's findings. The two Bochum wheels were removed from car 646 and an attempt was made to install them on car 631 in place of the wheels which had been returned to the manufacturer. Variances in axle size precluded this, however, and steel wheels were used instead.

After inspection and analysis by both the wheel and the rubber block manufacturers, the following was reported:

a. Both wheels were in safe operable condition, although high temperatures should be avoided.

b. The split rubber block in wheel 64419 does not inhibit the acoustical or structural qualities of the wheel and is not considered to be a failure

c. The damage to the two rubber blocks on wheel 64422 is not the direct result of overheating. Rather, rubber imperfections not detected by the manufacturer's quality control system were increased by a combination of high temperature and in-service compression stress, resulting in rubber damage.

d. Destruction of as many as three rubber blocks may be sustained by a Bochum wheel without danger of a failure. No predictions or assurances can be made concerning the structural integrity of a wheel if more than three blocks fail.

e. The integrity of the wheel can be assured only if operating temperatures do not exceed 200°C. No

predictions of time or temperature endurance at temperatures in excess of 200°C can be made.

Because dynamic brake failures do occur and SEPTA does not have a dynamic brake failure indication system and because of the temperatures experienced on car 631, operating temperatures less than 200°C could not be assured. Further, even with daily wheel inspections, there is no practical method of assuring that no more than three rubber blocks in a given wheel will fail in the course of a day. Consequently, SEPTA decided to permanently remove all Bochum wheels from revenue service.

The wheels on car 631 were changed out the week of June 5, 1977. Car 626 was kept in storage for use in the Phase III field tests. Upon completion of the tests, the Bochum wheels were removed and replaced by standard steel wheels. The Bochum wheels are being stored at SEPTA's 69th Street shop, pending disposition.

7.2.2 Acousta Flex Wheels

Acousta Flex wheels were installed on SEPTA cars 628 and 645 and on one axle of car 646. On February 1, 1977, after 10,647 miles of revenue service, a wheel, center serial no. 13, on car 628 was found to have failed. The resilient material between the steel rim and aluminum hub showed signs of breakage, the shunts at the back of the wheel had broken, the steel tire appeared to be winding off the aluminum center hub, and the rim was translating to the outer edge of the hub. No other wheels on either car showed evidence of failure.

Both cars 628 and 645 were removed from revenue service. After an on-site examination by the manufacturer, wheel 13 and its mate wheel, center serial no. 1, were returned to Standard

Steel for detailed testing to determine the cause of failure and to establish a level of confidence in the remaining wheels. The remaining Acousta Flex wheels on car 628 were replaced with steel wheels, and the car was returned to service. Car 645 was placed in storage pending the results of Standard Steel's investigation.

In a meeting held April 13, 1977, the manufacturer verbally reported that the analysis and testing to date had established that an adhesion failure between the resilient elastomer and the steel rim had indeed occurred. The tire had rotated 120 degrees with respect to the aluminum hub and a 0.167 inch axial translation of the rim outward from the aluminum center was measured.

In a report dated June 29, 1977, Standard Steel reached the following conclusion concerning the failed wheel:

> "Rotation of #13's rim and tire unit relative to the center was attributed to lack of bond on the steel rim. Analysis of a foreign material at the silicone - rim interface showed this substance to be silicone which has been abraded and compacted under alternating loads. Early indications that rotation may have been related to overheating proved to be spurious. The ... temperature indicator on the rim was shown to have malfunctioned. The tread had, however, been subjected to localized frictional heating in excess of the transformation range (1350°F.). This was evident from the thermal checks, spalling, and transformed microstructure at the surface. The mate wheel exhibited a similar appearance.

> "No definite cause could be identified with the poor bond on the rim of the rotated wheel. It is believed that only partial bonding existed at the time of manufacture. Once fully bonded, it is virtually impossible to remove silicone from a primed substrate. Apparently some weak adhesion formed, giving the appearance of a satisfactory bonding. These partial bonds evidently were broken under the influence of service related cyclic loads.

"Of the eighteen (18) wheels, it is understood that two (2) carsets (sic) have had approximately equal service, i.e., over 11,000 miles. Thorough visual examination of the other seventeen wheels showed no evidence of degradation of the adhesive bonds. This leads to the conclusion that the poor bond condition on Serial #13 is an isolated case. The high shear values demonstrated by the mate wheel (as determined by sectioning and shear testing) is another indication that the bond integrity of the remaining wheels is satisfactory."

Car 645 remained in storage and was utilized during the Phase III field tests. Upon completion of the field tests, the Acousta Flex wheels were replaced by steel wheels and the car returned to revenue service.

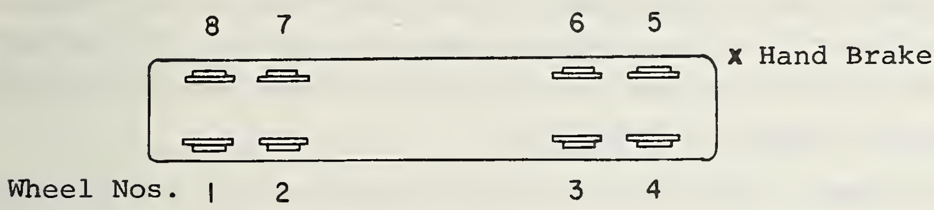
7.2.3 SAB Wheels

SAB Wheels were installed on SEPTA cars 609 and 630 and on one axle of car 646. Sometime during the morning of August 4, 1977, the handbrake on car 609 was applied while the car was in revenue service. The SEPTA handbrake consists of a chain linkage connecting to the tread brakes of the pair of wheels nearest the brake. When the handbrake is applied, the tread brakes are placed against the wheels; and if the vehicle moves, the wheels ca[n] become overheated. In the case of resilient wheels, this results in the disintegration of the rubber inserts and the ultimate failure of the wheels.

Upon noticing this failure, SEPTA had both cars containing SAB wheels removed from service. Car 609 was set aside in the yard for inspection by SEPTA and DCO personnel. Car 630 was put into the shop where the SAB wheels were removed and replaced by steel wheels. De Leuw, Cather was informed of this incident on Friday, August 5.

On Monday, August 8, De Leuw, Cather personnel inspected the wheels and took a number of photographs. Figure 7-1 depicts the configuration of car 609.

Figure 7-1. SAB Car 609



Wheel No. 6 was most severely damaged, the shunts were broken off, the majority of visible rubber inserts were disintegrated and rubber residue coated the wheel in several locations. The cover plate for the rubber inserts had dropped and was resting against the wheel flange. It appeared, however, that the wheel was still structurally sound as no failures were found in the main bolt system. The temperature tape was severely burned.

The damage to wheel No. 5 was less severe. Although the temperature tape was severely burned and some disintegration of rubber inserts was noticeable, the shunts remained intact and the cover plate had not dropped.

The difference in the level of damage to the two wheels was apparently caused by a higher frictional force existing between the brake and tread of wheel No. 6 than wheel No. 5.

There was no apparent damage to the other wheels on car 609. The temperature tapes of the other wheels exhibited similar readings to those noted during the Phase III tests several weeks earlier.

Upon completion of the inspection, all wheels on car 609 were replaced by steel wheels, and the car was returned to revenue service.

7.3 ADDITION OF RING DAMPED WHEELS

At the APTA Workshop No. 3, held April 13, 1977, it was suggested that steel ring damped wheels be added to the test program in lieu of the viscoelastic damped wheels. All parties agreed, and procedures were initiated to include the wheels in the subsequent phases of testing.

Boeing Vertol Company was contacted concerning the use of their ring damped wheel design developed for use on the CTA cars. Boeing Vertol ultimately agreed and furnished sketches and details for adapting the ring damped wheel design to SEPTA wheels. Fabrication of the steel ring dampers and the machining of grooves into SEPTA's wheels is being performed by Standard Steel Company.

A two-car set of ring damped wheels will be included in the Phase IV, V, and VI test program.

7.4 ADDITIONAL PROPULSION SYSTEM NOISE TESTS

The data obtained from the first two phases of testing contained numerous anomalies including less than anticipated reductions in noise levels for welded track as compared to jointed track, for trued wheels as compared to worn wheels, and for ground rail as compared to unground rail. It was postulated that a number of the anomalies might be caused by the relative similarity of the wheel/rail and propulsion system noise levels. In an attempt to resolve this situation, it was decided to measure the noise levels of the propulsion system of each vehicle in the test program in order to determine the differences which exist, if any. These measurements will be taken with the vehicles supported on blocks with the wheels allowed to spin freely and with the engines running in both the series and parallel mode.

8. SUMMARY OF REMAINING WORK

This report has presented the acoustical data and preliminary results from the first three phases of field testing; the information gathered from the survey of transit systems, equipment, and wheel manufacturers; the equations for determining the present value of the life-cycle costs for resilient and solid-steel wheels, wheel truing, and rail grinding; and the initial analysis of the cost effectiveness of each technique.

The work remaining to be performed includes the final three phases of field testing, the gathering of the remaining data from the transit systems, the completion of the analysis of the cost effectiveness of the noise control techniques and the preparation of the final report.

8.1 FIELD TESTING

The final three phases of field testing will be performed during November 1977 and will include wayside and interior noise measurements for the two-car set of worn standard steel wheels, the two-car set of new/trued standard steel wheels, and a two-car set of ring damped solid steel wheels.

Phase IV testing will include wayside measurements at the TURN, TW, TJ, and SUB3 test segments and interior measurements at all test locations. The general purpose of the Phase IV tests will be to measure the noise levels of the worn and new/trued wheels after one year of in-service testing to determine if any significant changes in noise levels have occurred during this period.

Upon completion of Phase IV, the test sections of the TURN, TW, TJ, SUB1, SUB2, and SUB3 segments will be ground and the wayside and interior noise levels will be measured again to determine the effects of rail grinding and to compare the results of this phase of the program with the data from the previous rail grinding effort.

Upon completion of the Phase V tests, the wheels on all car sets will be trued and wayside and interior noise measurements will be taken on the TURN and TW test segments to determine the effect of wheel truing and to compare the results with the data from the previous wheel truing effort. The additional propulsion system noise tests will also be performed at this time.

8.2 SURVEY OF TRANSIT SYSTEMS

The data still outstanding from a number of the transit systems will be gathered and system descriptions and cost charts will be prepared for BART and the TTC. The data and cost information contained in this report will be reviewed by the transit properties for correctness and will be revised as required.

8.3 COST EFFECTIVENESS ANALYSIS

The cost data for each of the transit systems will be subjected to a computer analysis using the life-cycle equations. A matrix will be prepared showing the present value of the life-cycle costs for the noise reduction techniques used by each system.

8.4 FINAL REPORT

A final report will be prepared in the format outlined in the Experimental Design Interim Report* and will include the following:

a. A method to predict the results of using the various equipment and techniques on any U.S. rail transit system. This shall address, as a minimum, prediction of numerical values and confidence limits for the evaluation parameters to characterize acoustic performance over time for station, in car, and community, and to estimate life-cycle costs.

*Michael C. Holowaty, Hugh H. Saurenman, and Stanley M. Rosen, "In-Service Performance and Costs of Methods for Control of Urban Rail System Noise - Experimental Deisgn," Report No. UMTA-MA-06-0025-76-4,May 1976. (NTIS No. PB 257-200).

b. Recommendations for possible improvements in design or use of the equipment and recommendations for additional data collection or analysis.

c. The major considerations in the development of the Experimental Design and the T&E plan. The main features of the original design and plan and departures from it.

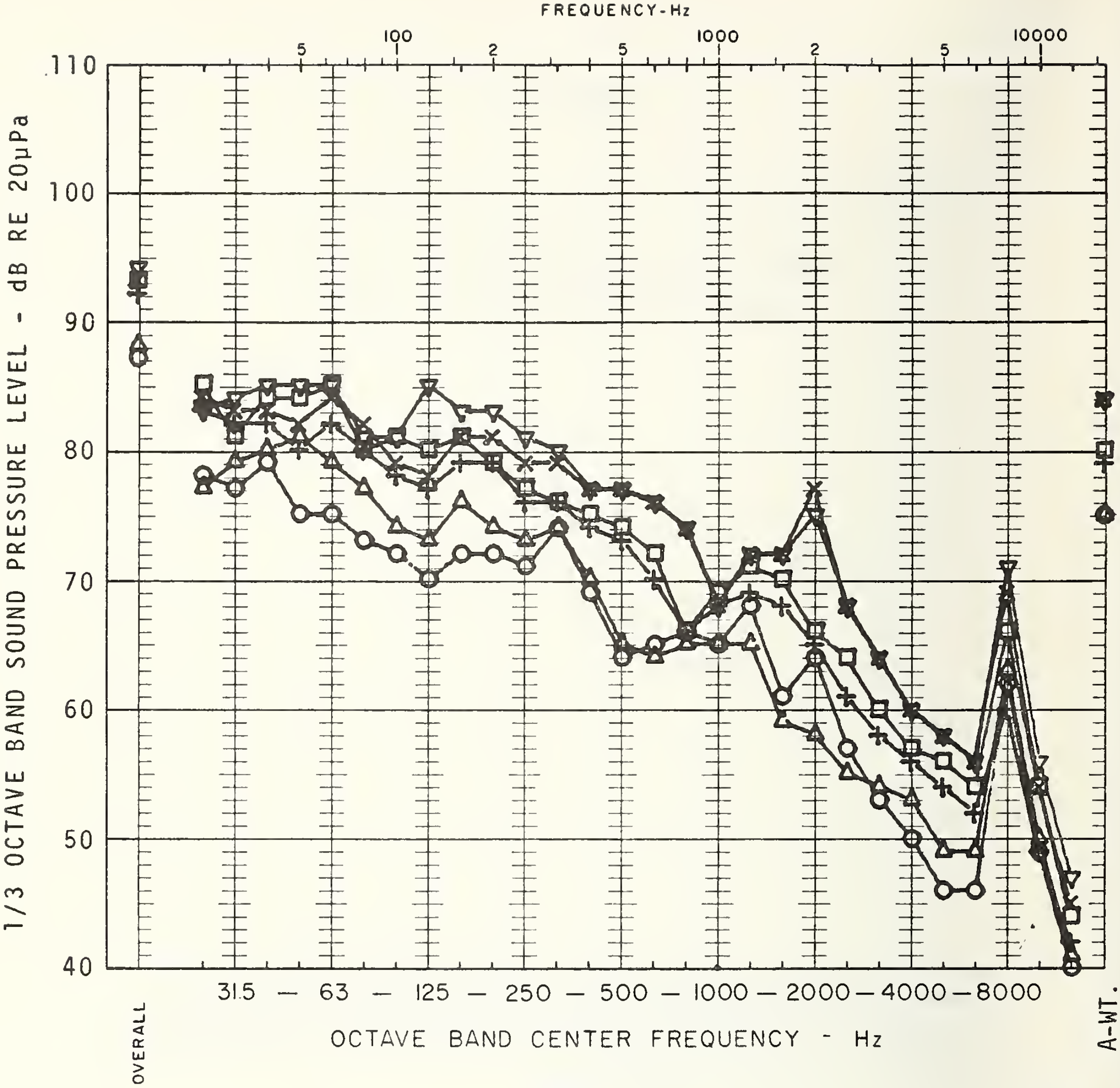
d. For each type of wheel and each type of rail grinding and wheel truing equipment: a listing of the evaluation parameters identified in the Experimental Design and T&E plan, the numerical values determined for the parameters on the SEPTA system, confidence limits on those values, a list of possible constraints on compatibility conditions where appropriate.

e. A discussion of the probable importance of the various evaluation parameters, of trends observed including cost and performance as a function of time, weather, and other operating conditions. A comparison of actual performance with expected behavior based on current theoretical models. A discussion of possible cost-effective strategies for use of the equipments.

APPENDIX A

SPECTRA OF MEASUREMENTS ON TANGENT WELDED BALLAST AND TIE TRACK*

*Spectra include wayside and car interior measurements for worn-standard and new-standard wheels for Test Phases IA, IB, & IC; and wayside and car interior measurements for the trued-standard, Acoustaflex, Bochum & SAB wheels for Test Phase IIA. Notch filter used on all spectra in Appendix A.

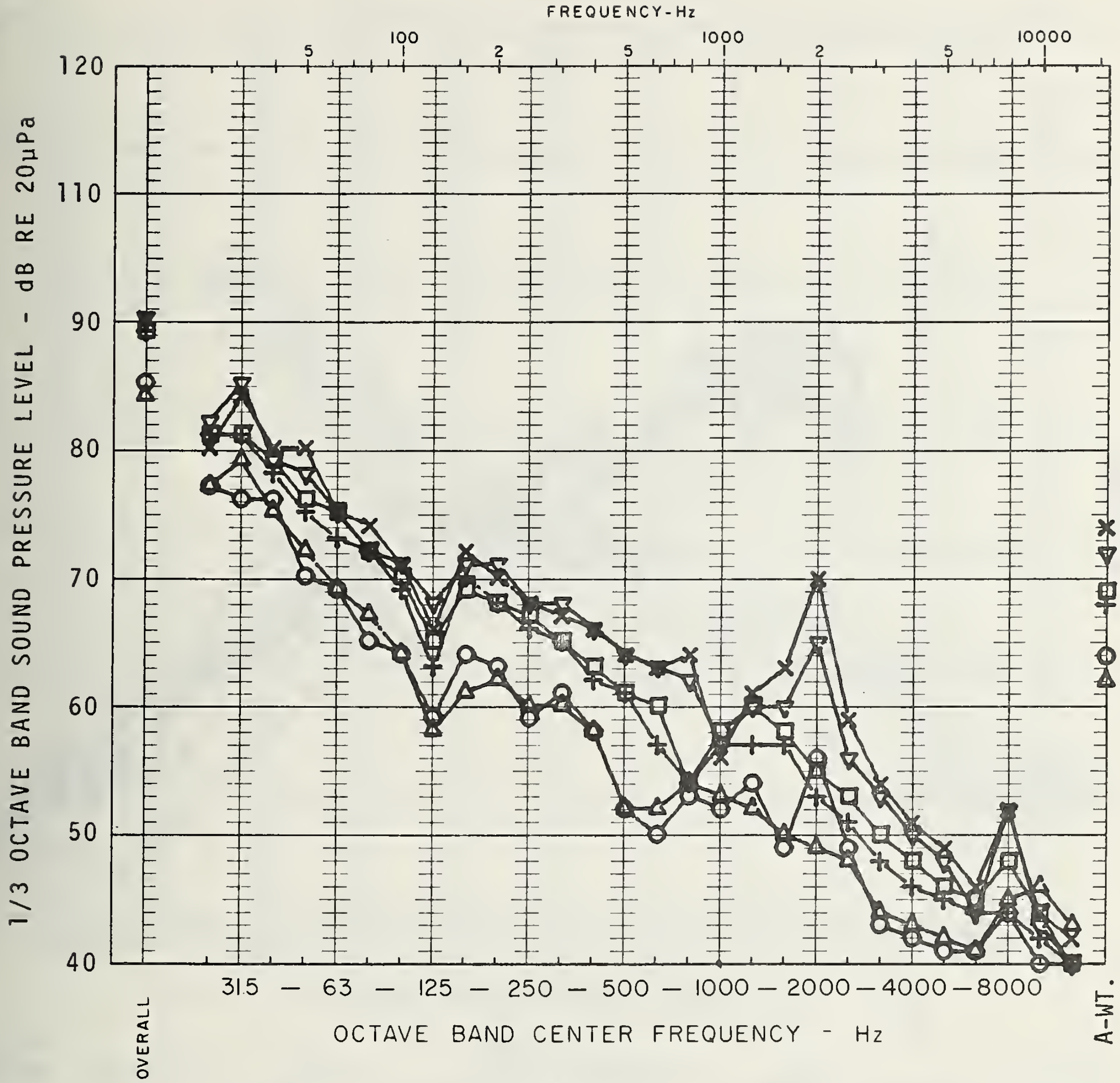


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	NORMAL	75	△——△	REVERSE	42
+——+	REVERSE	56	▽——▽	NORMAL	78
□——□	NORMAL	62			
○——○	NORMAL	41			

FIGURE A-1. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE 1A; JULY 14, 1977

CAR INTERIOR, OVER TRUCK - WORN STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	NORMAL	75	△—△	NORMAL	42
+—+	REVERSE	56	▽—▽	REVERSE	78
□—□	NORMAL	62			
○—○	REVERSE	41			

FIGURE A-2. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IA; JULY 14, 1976

CAR INTERIOR, OVER TRUCK - WORN STANDARD WHEELS

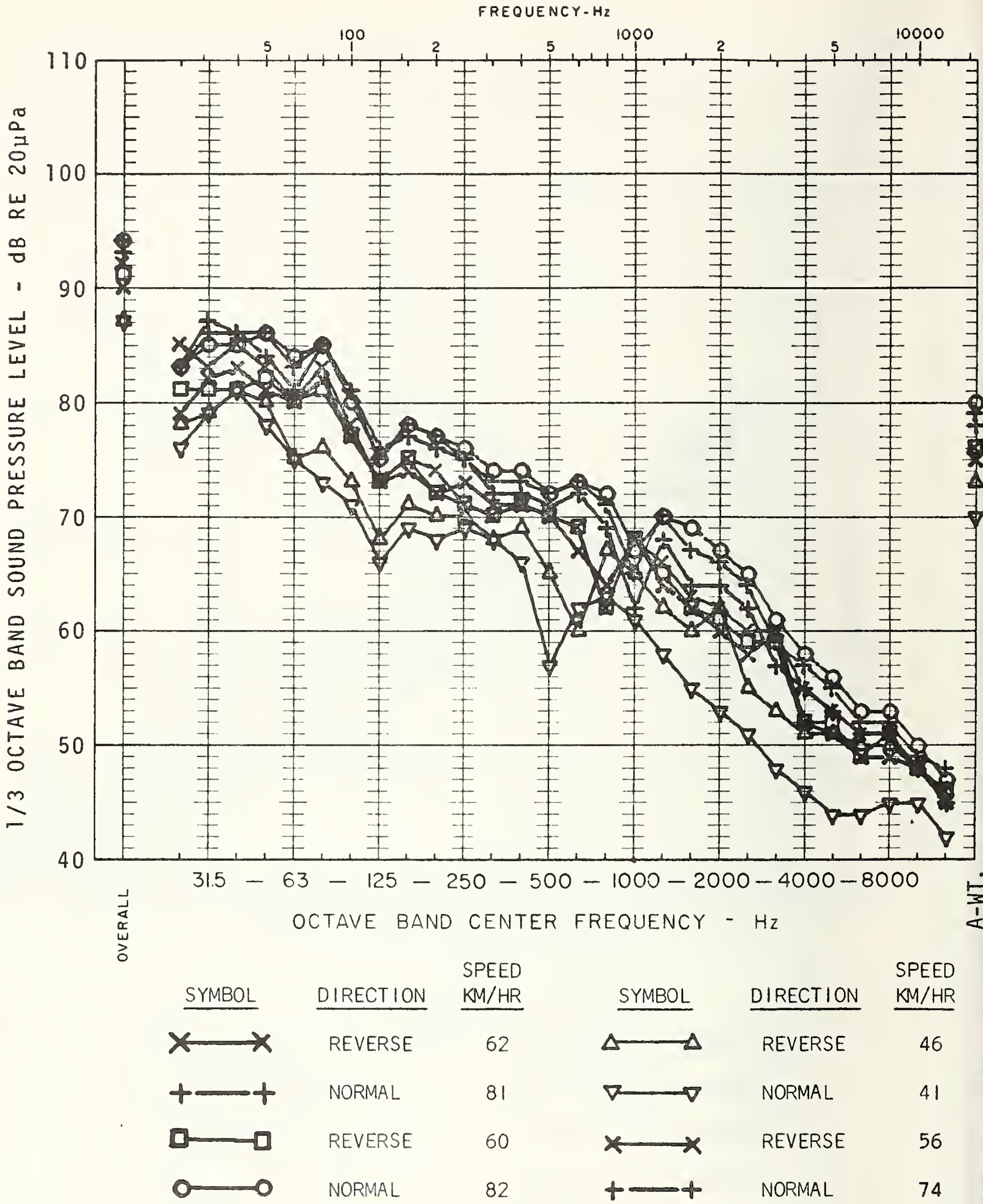
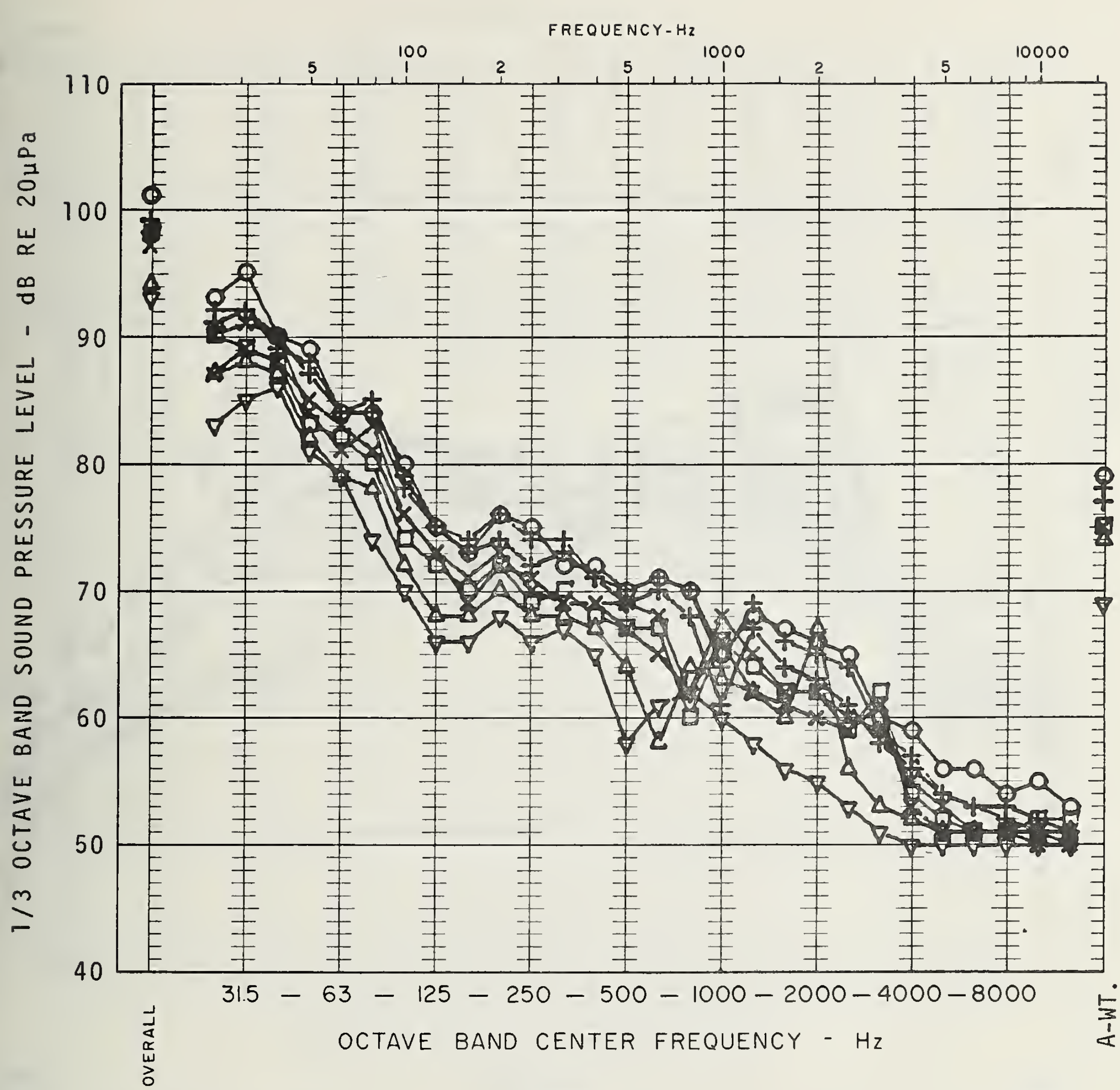


FIGURE A-3. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IA; JULY 14, 1976

CAR INTERIOR, OVER TRUCK - NEW STANDARD WHEELS

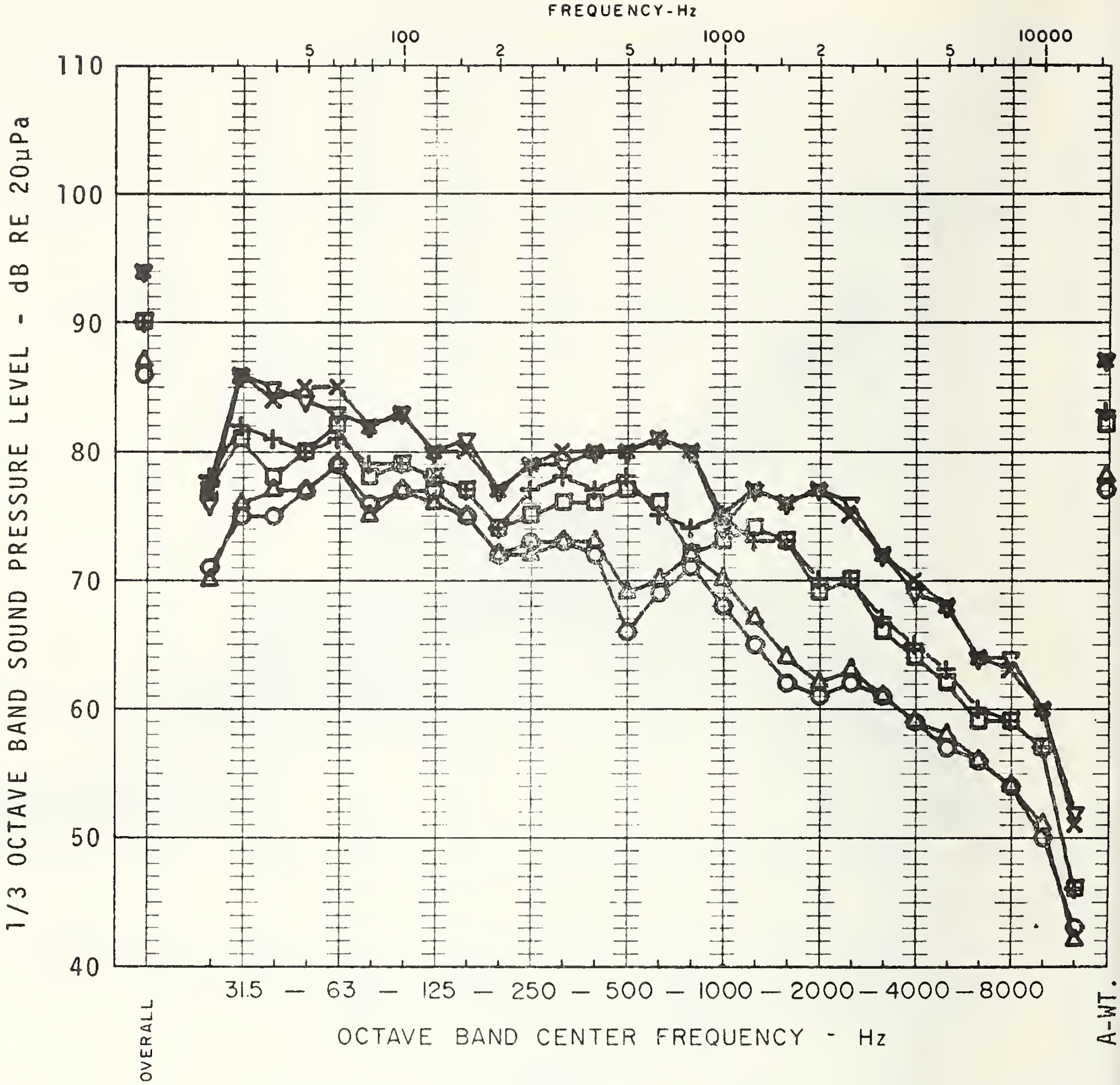


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	62	△——△	REVERSE	46
+——+	NORMAL	81	▽——▽	NORMAL	41
□——□	REVERSE	60	×——×	REVERSE	56
O O	NORMAL	82	+——+	NORMAL	74

FIGURE A-4. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IA; JULY 14, 1976

CAR INTERIOR AT CENTER - NEW STANDARD WHEELS

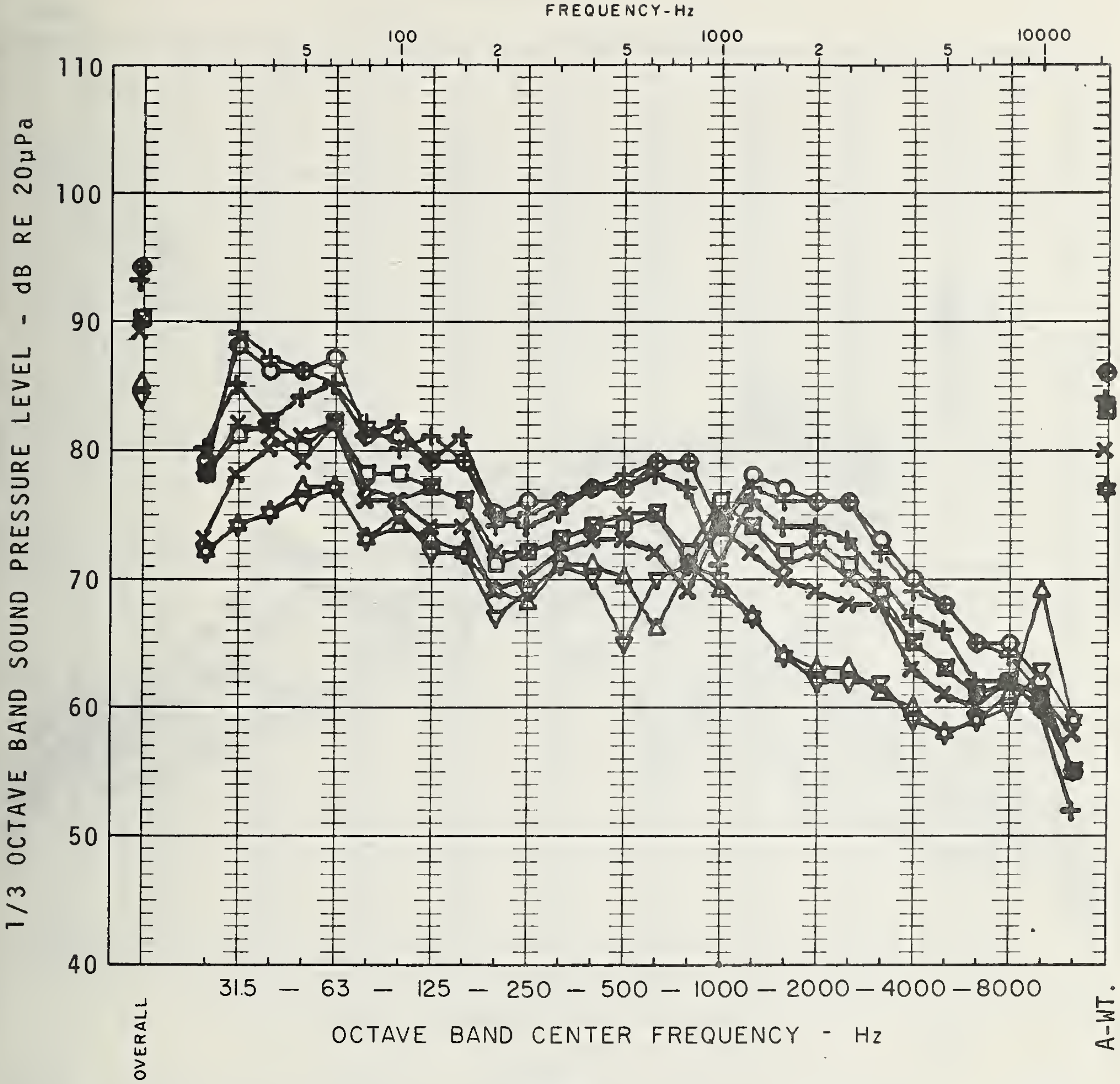


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	NORMAL	78	△——△	NORMAL	42
+——+	REVERSE	56	▽——▽	REVERSE	78
□——□	NORMAL	62			
○——○	REVERSE	41			

FIGURE A-5. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IA; JULY 14, 1976

WAYSIDE - WORN STANDARD WHEELS

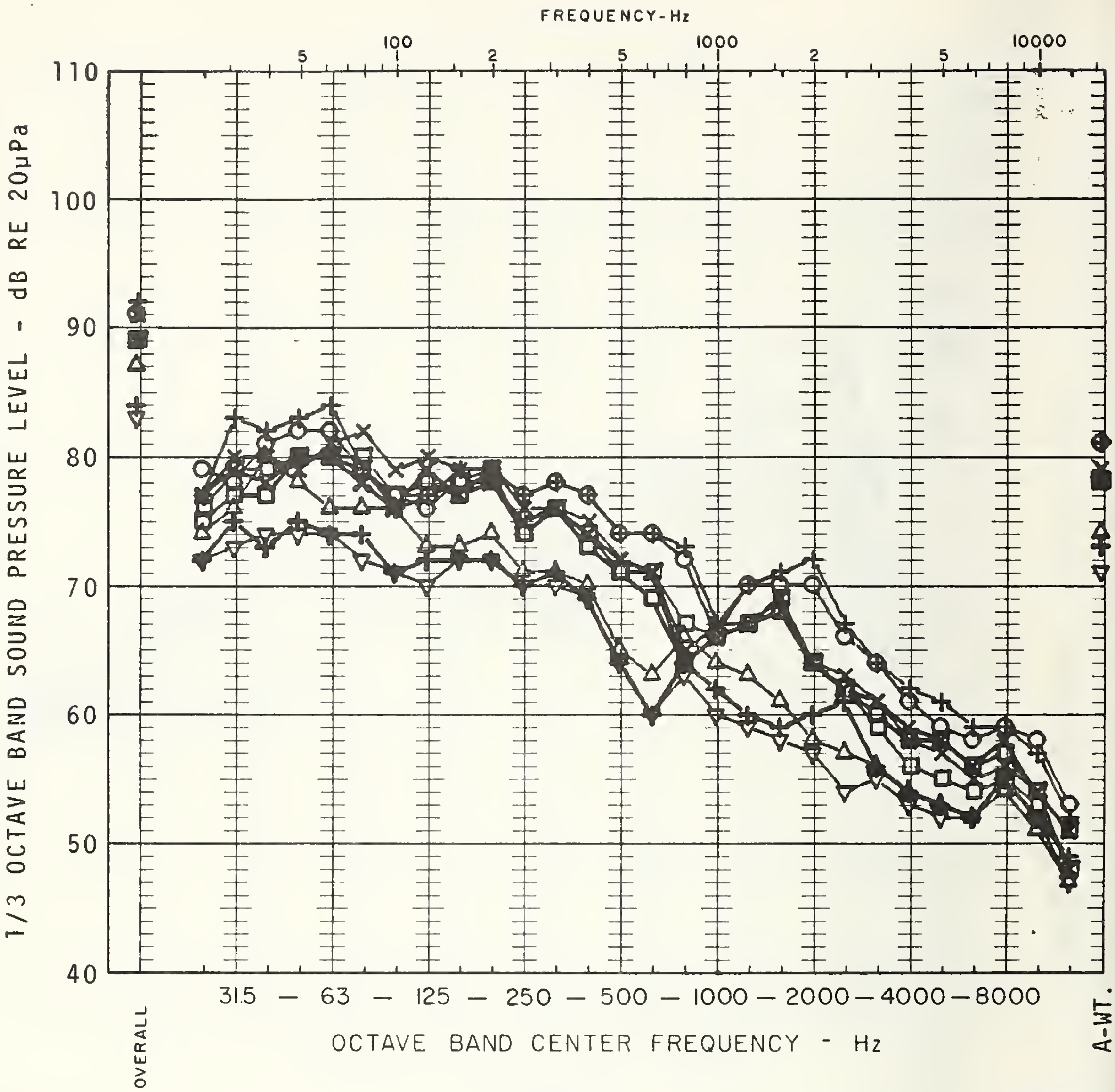


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×———×	REVERSE	62	△———△	REVERSE	46
+———+	NORMAL	81	▽———▽	NORMAL	41
□———□	REVERSE	60	×———×	REVERSE	56
○———○	NORMAL	82	+———+	NORMAL	74

FIGURE A-6. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IA; JULY 14, 1976

WAYSIDE - NEW STANDARD WHEELS

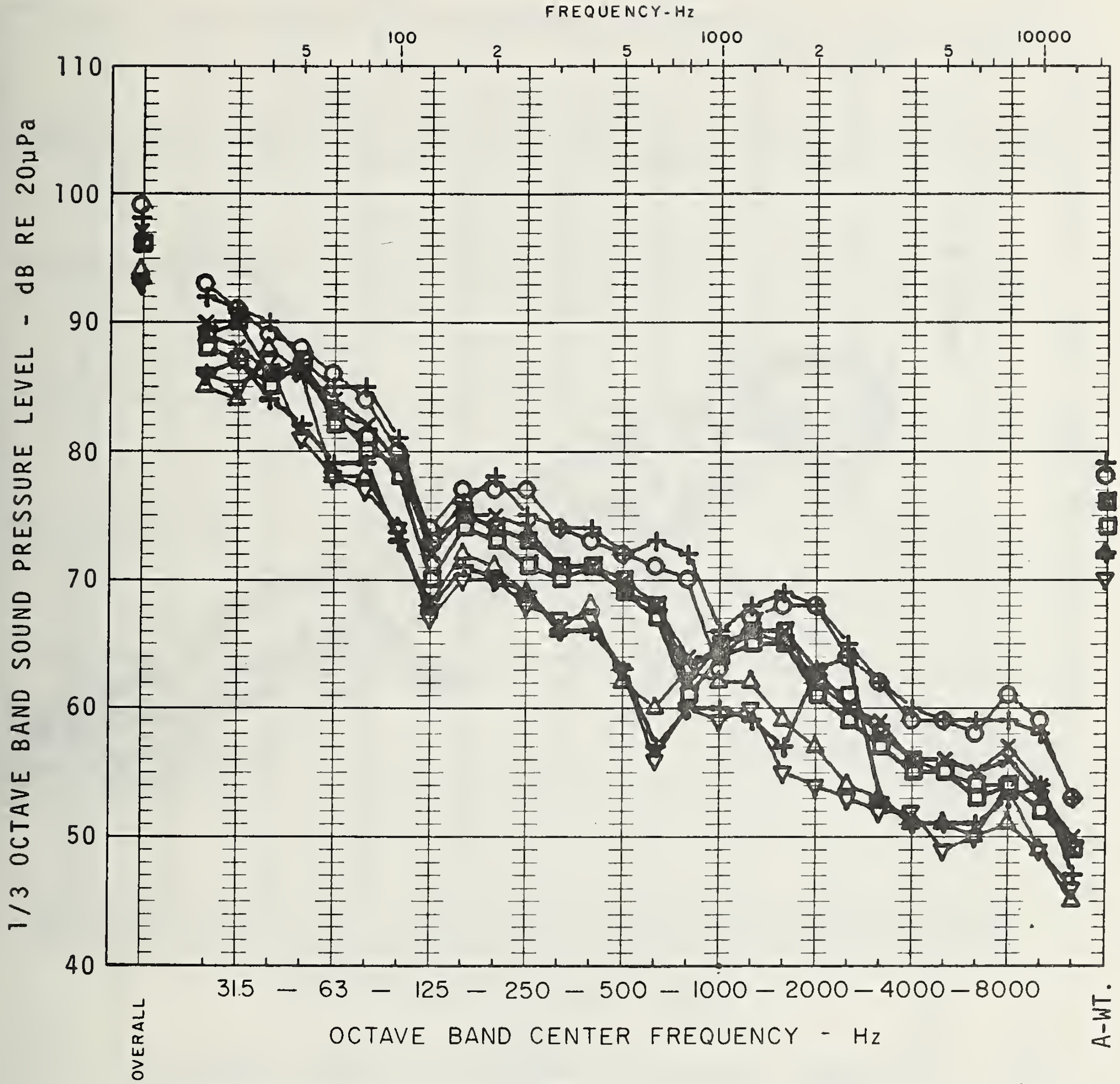


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	63	△——△	REVERSE	43
+——+	NORMAL	79	▽——▽	NORMAL	44
□——□	REVERSE	64	×——×	REVERSE	63
○——○	NORMAL	78	+——+	NORMAL	45
			□——□	REVERSE	62

FIGURE A-7. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IB; AUGUST 17, 1976

CAR INTERIOR, OVER TRUCK - WORN STEEL WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	63	△——△	REVERSE	43
+——+	NORMAL	79	▽——▽	NORMAL	44
□——□	REVERSE	64	×——×	REVERSE	63
○——○	NORMAL	78	+——+	NORMAL	45
			□——□	REVERSE	62

FIGURE A-8. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IB; AUGUST 17, 1976

CAR INTERIOR AT CENTER - WORN STEEL WHEELS

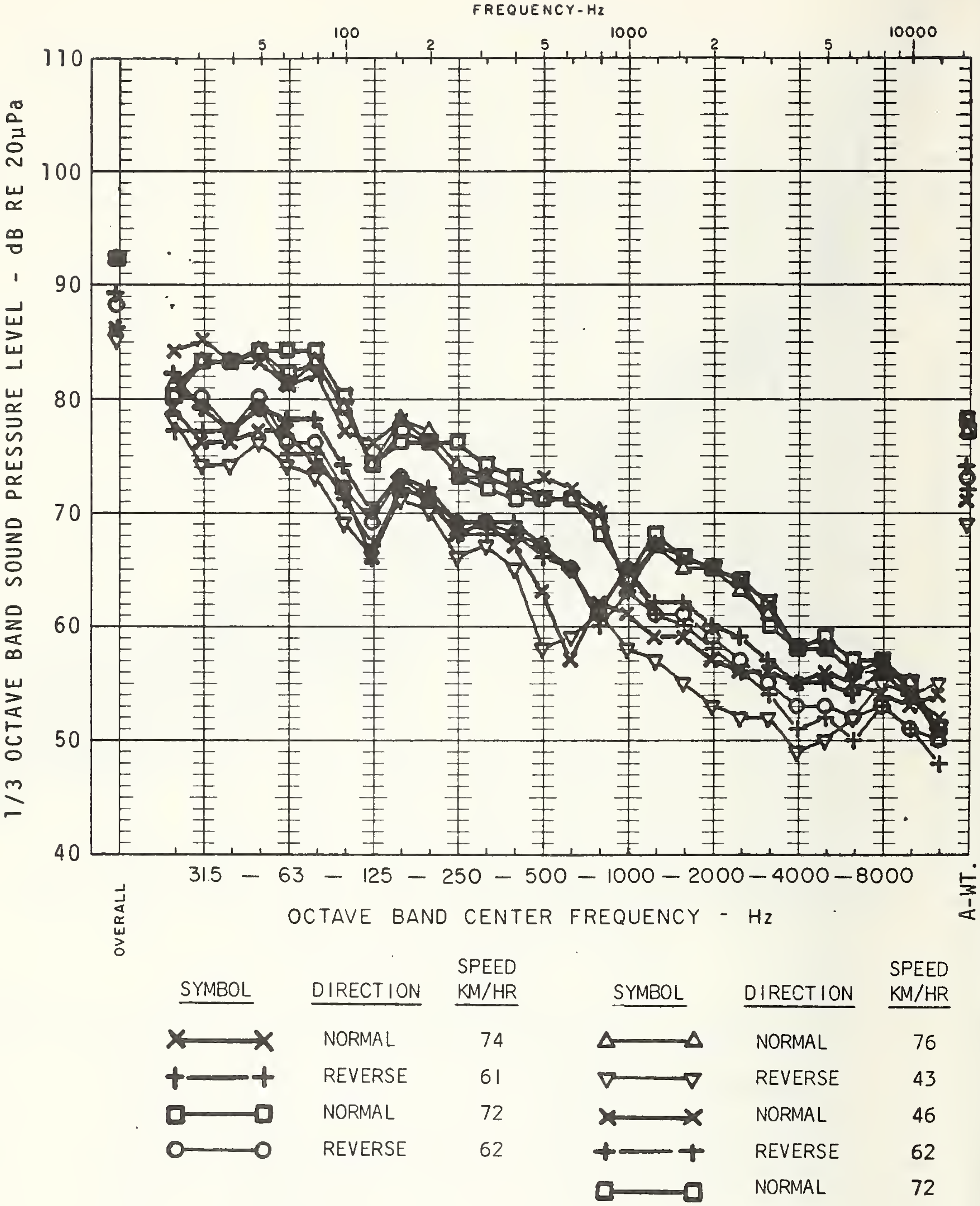
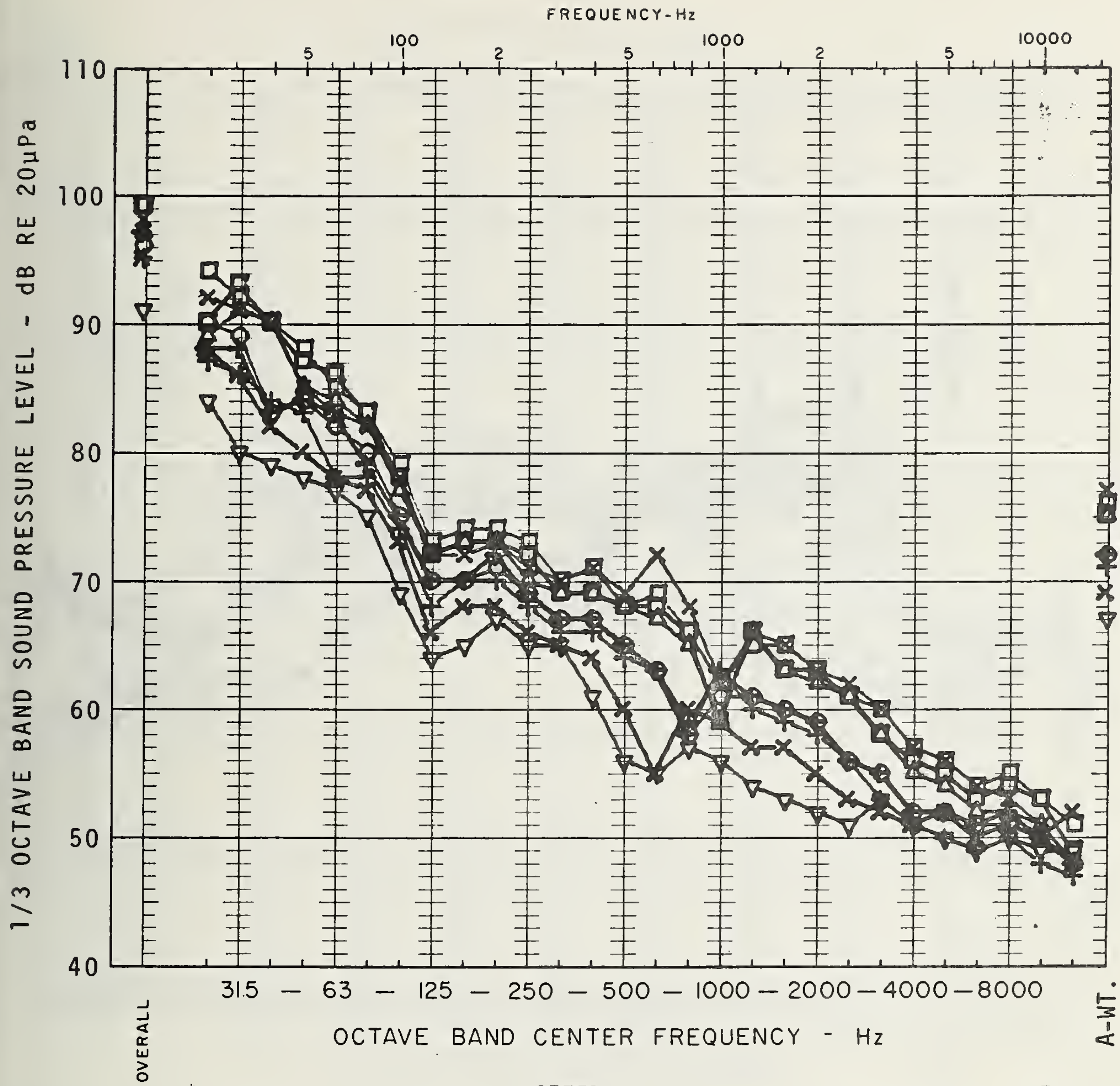


FIGURE A-9. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IB; AUGUST 17, 1976

CAR INTERIOR, OVER TRUCK - NEW STANDARD WHEELS

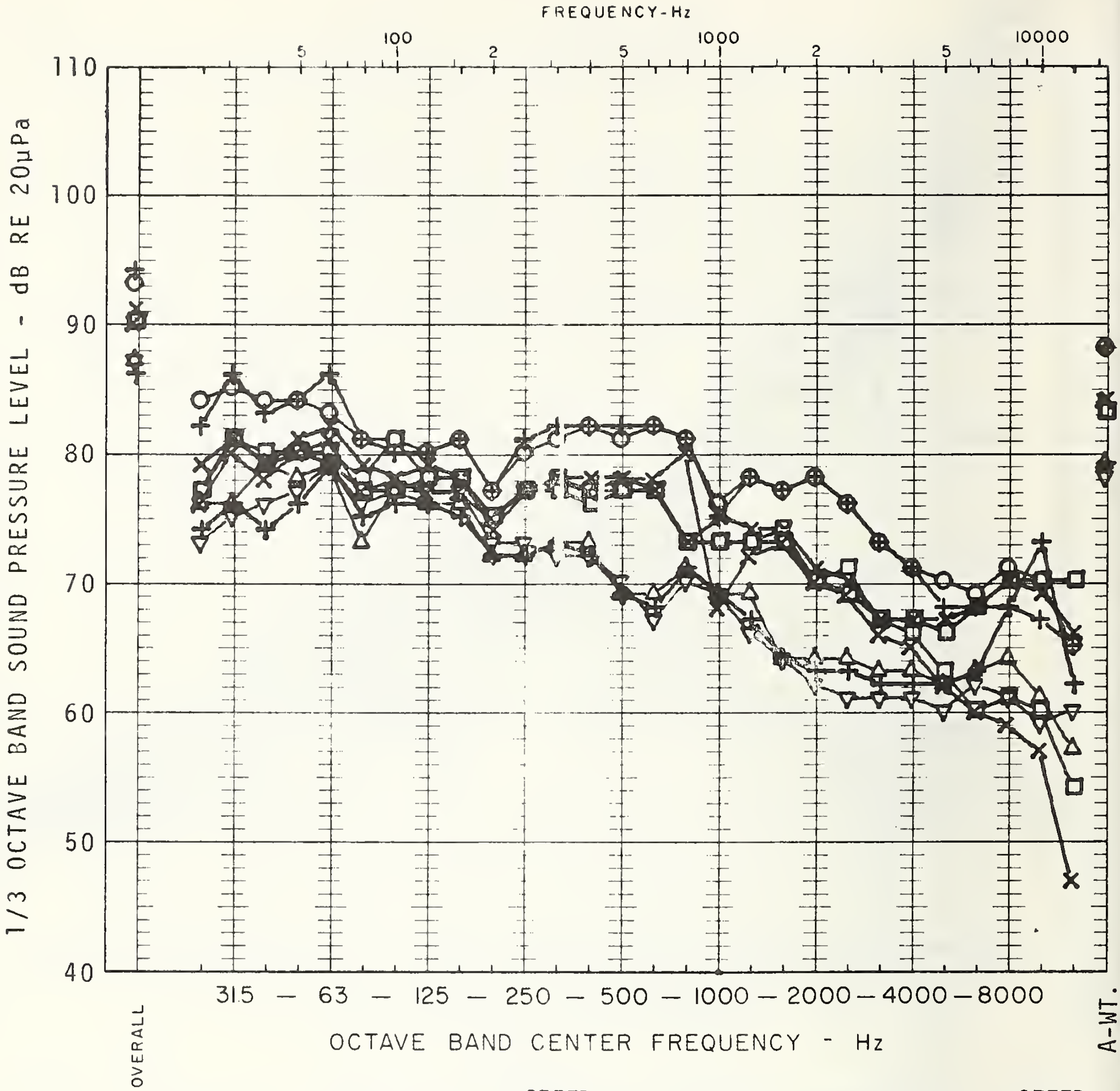


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	NORMAL	74	△——△	NORMAL	76
+——+	REVERSE	61	▽——▽	REVERSE	43
□——□	NORMAL	72	×——×	NORMAL	46
○——○	REVERSE	62	+——+	REVERSE	62
			□——□	NORMAL	76

FIGURE A-10. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IB; AUGUST 17, 1976

CAR INTERIOR AT CENTER - NEW STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	63	△——△	REVERSE	43
+——+	NORMAL	79	▽——▽	NORMAL	44
□——□	REVERSE	64	×——×	REVERSE	63
○——○	NORMAL	78	+——+	NORMAL	45
			□——□	REVERSE	62

FIGURE A-11. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IB; AUGUST 17, 1976

WAYSIDE - WORN STANDARD WHEELS

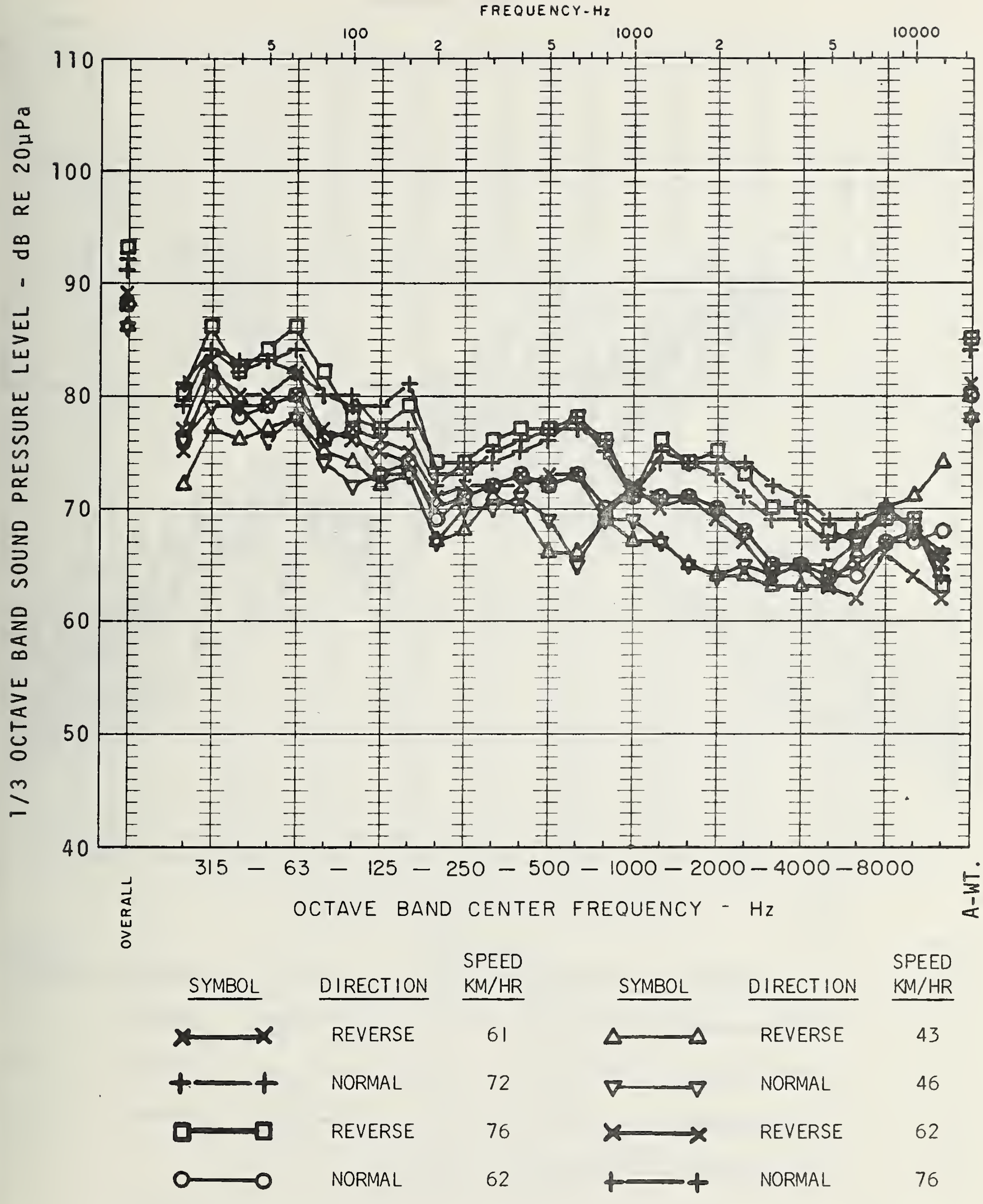
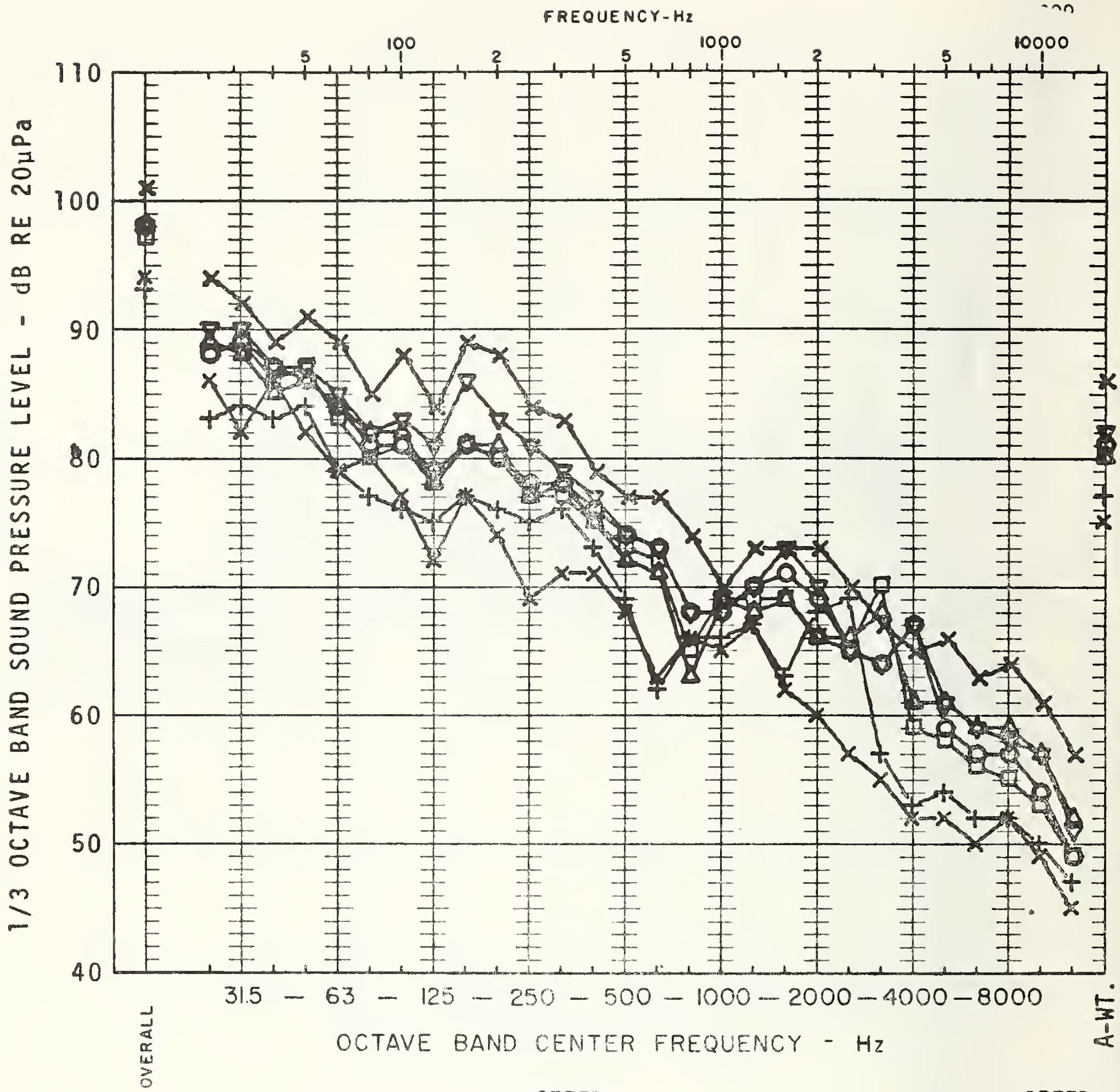


FIGURE A-12. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IB; AUGUST 17, 1976

WAYSIDE - NEW STANDARD WHEELS

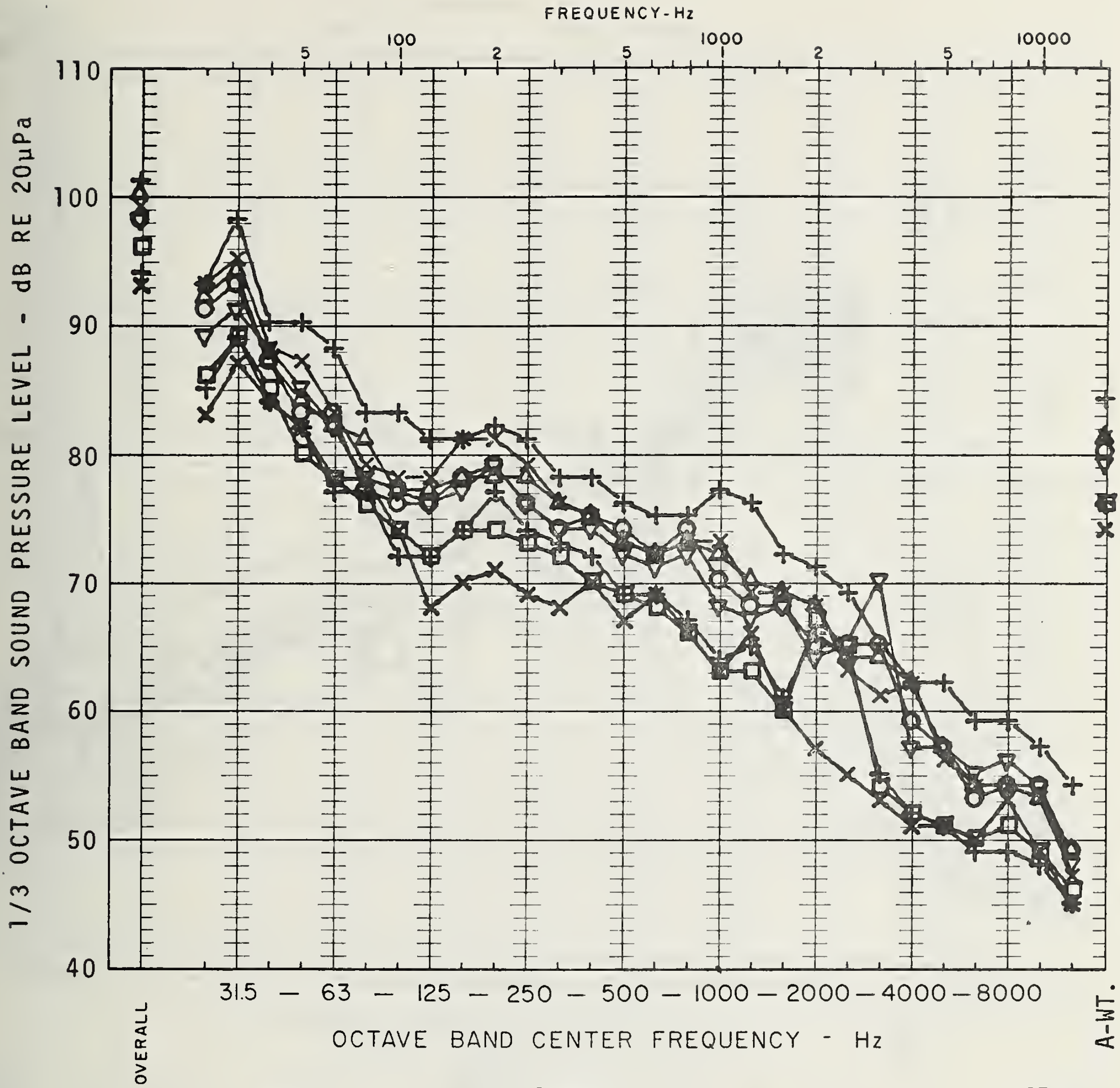


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
X———X	NORMAL	46	△———△	NORMAL	59
+———+	REVERSE	48	▽———▽	REVERSE	66
□———□	REVERSE	60	x———x	NORMAL	80
O———O	REVERSE	66			

FIGURE A-13. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IC; SEPTEMBER 2, 1976

CAR INTERIOR, OVER TRUCK - WORN STANDARD WHEELS

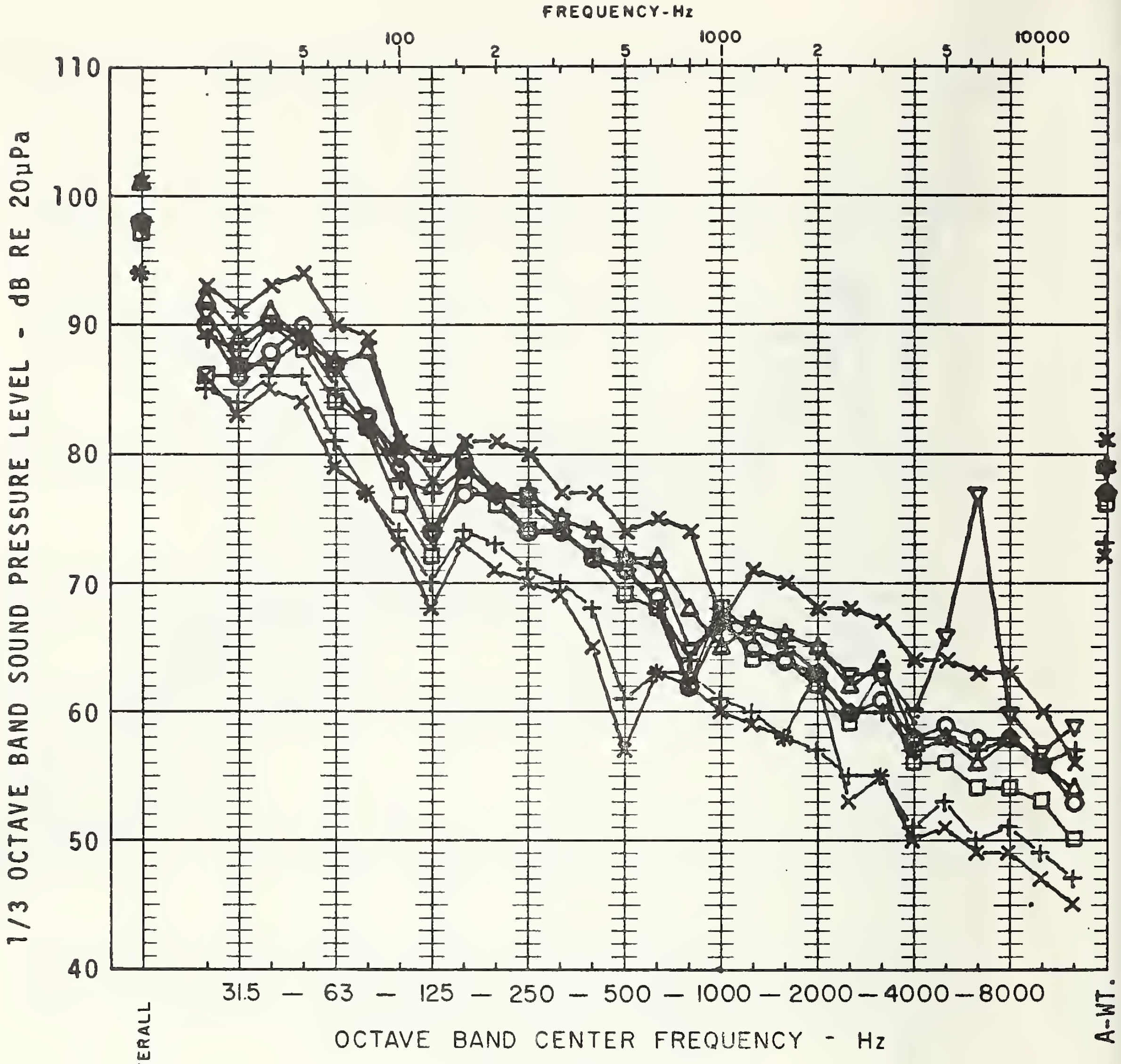


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
X——X	NORMAL	46	△——△	REVERSE	66
+——+	REVERSE	48	▽——▽	NORMAL	59
□——□	NORMAL	44	×——×	REVERSE	66
○——○	REVERSE	60	+——+	NORMAL	80

FIGURE A-14. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IC; SEPTEMBER 2, 1976

CAR INTERIOR AT CENTER - WORN STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
✕—✕	NORMAL	39	△—△	NORMAL	70
+—+	REVERSE	42	▽—▽	REVERSE	64
□—□	NORMAL	58	×—×	NORMAL	81
○—○	REVERSE	59	+—+	REVERSE	56

FIGURE A-15. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IC; SEPTEMBER 2, 1976

CAR INTERIOR, OVER TRUCK - TRUED STANDARD WHEELS

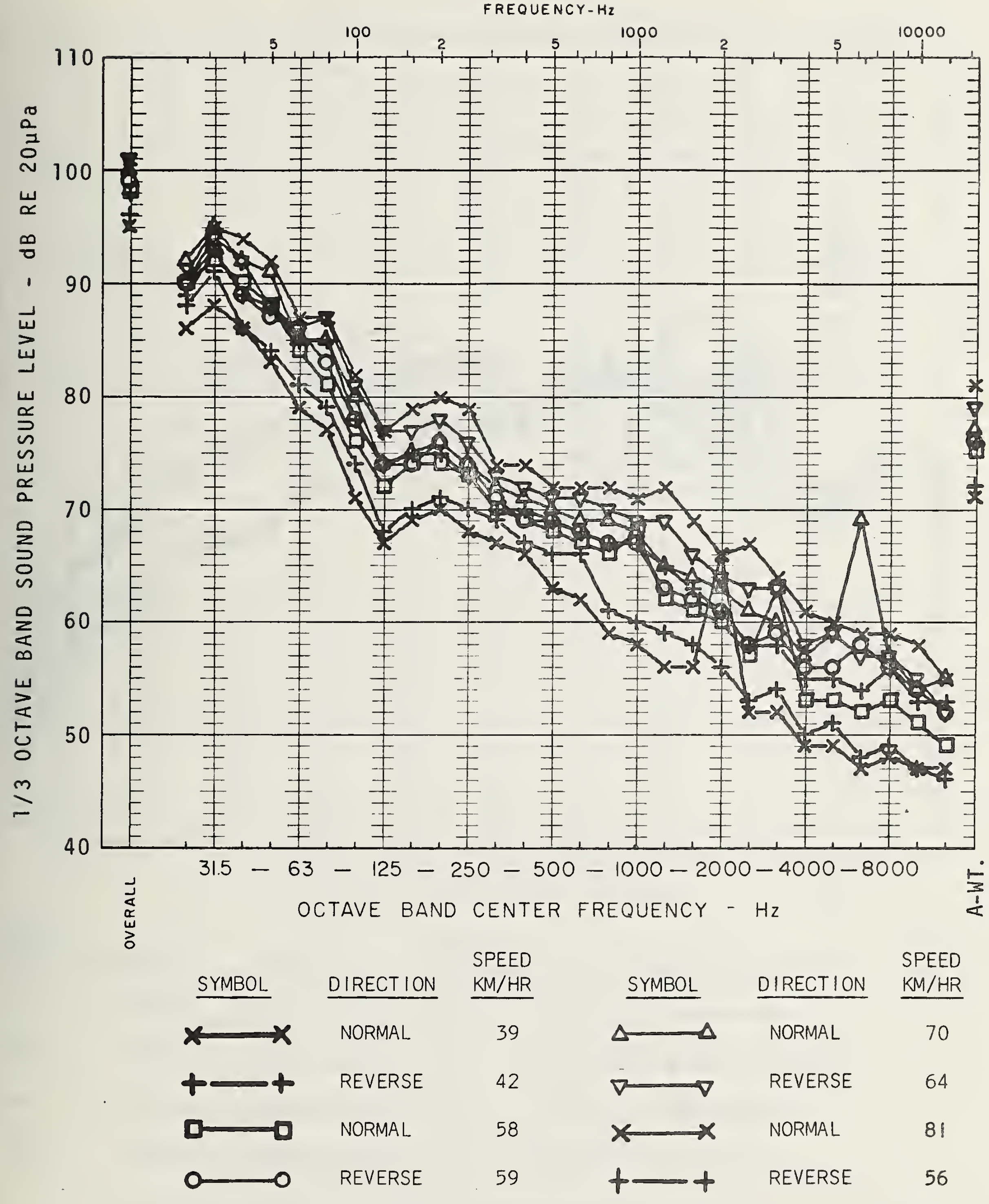
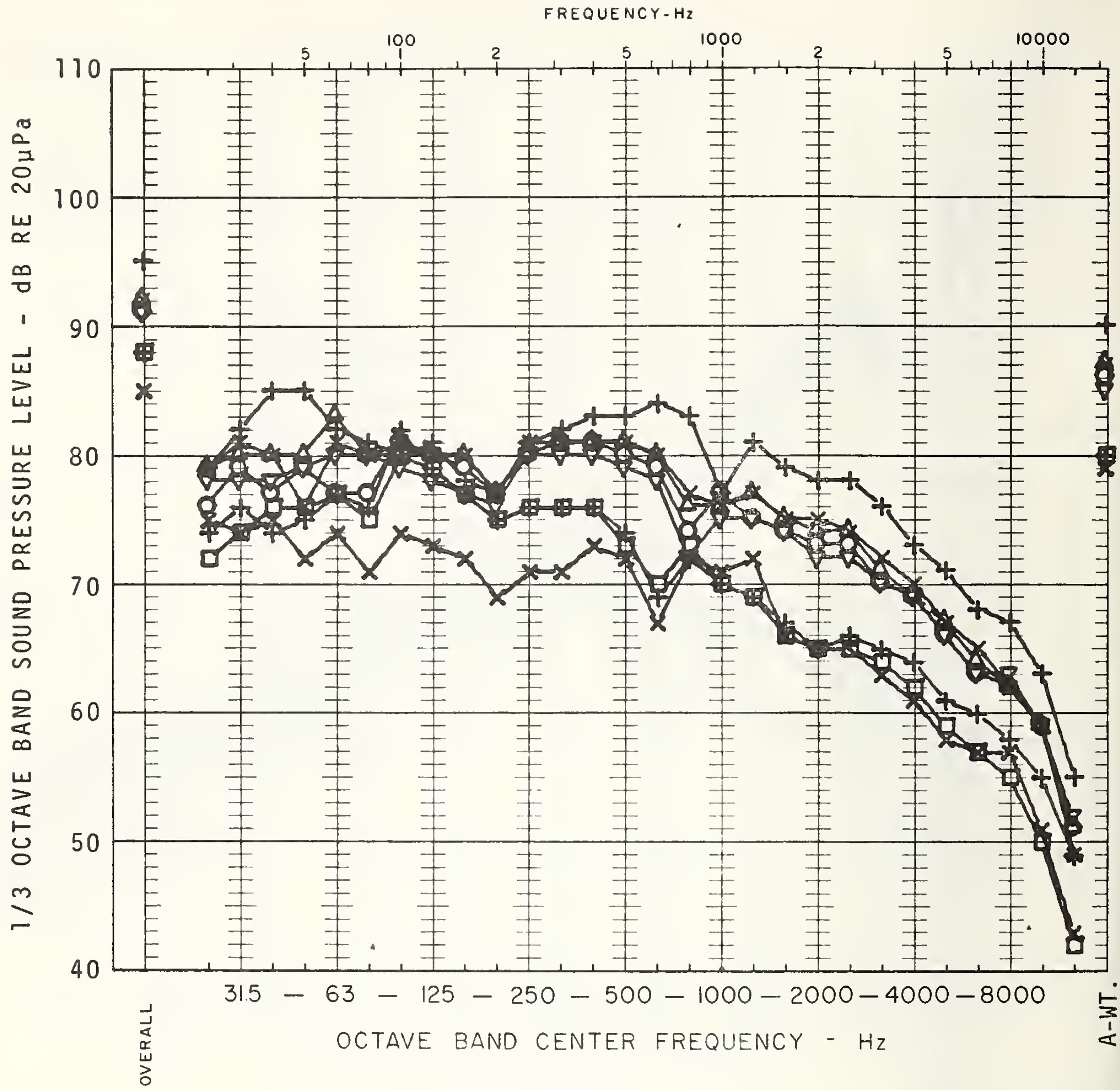


FIGURE A-16. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IC; SEPTEMBER 2, 1976

CAR INTERIOR AT CENTER - TRUED STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
X———X	NORMAL	46	△———△	REVERSE	66
+———+	REVERSE	48	▽———▽	NORMAL	59
□———□	NORMAL	44	×———×	REVERSE	66
○———○	REVERSE	60	+———+	NORMAL	80

FIGURE A-17. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IC; SEPTEMBER 2, 1976

WAYSIDE - WORN STANDARD WHEELS

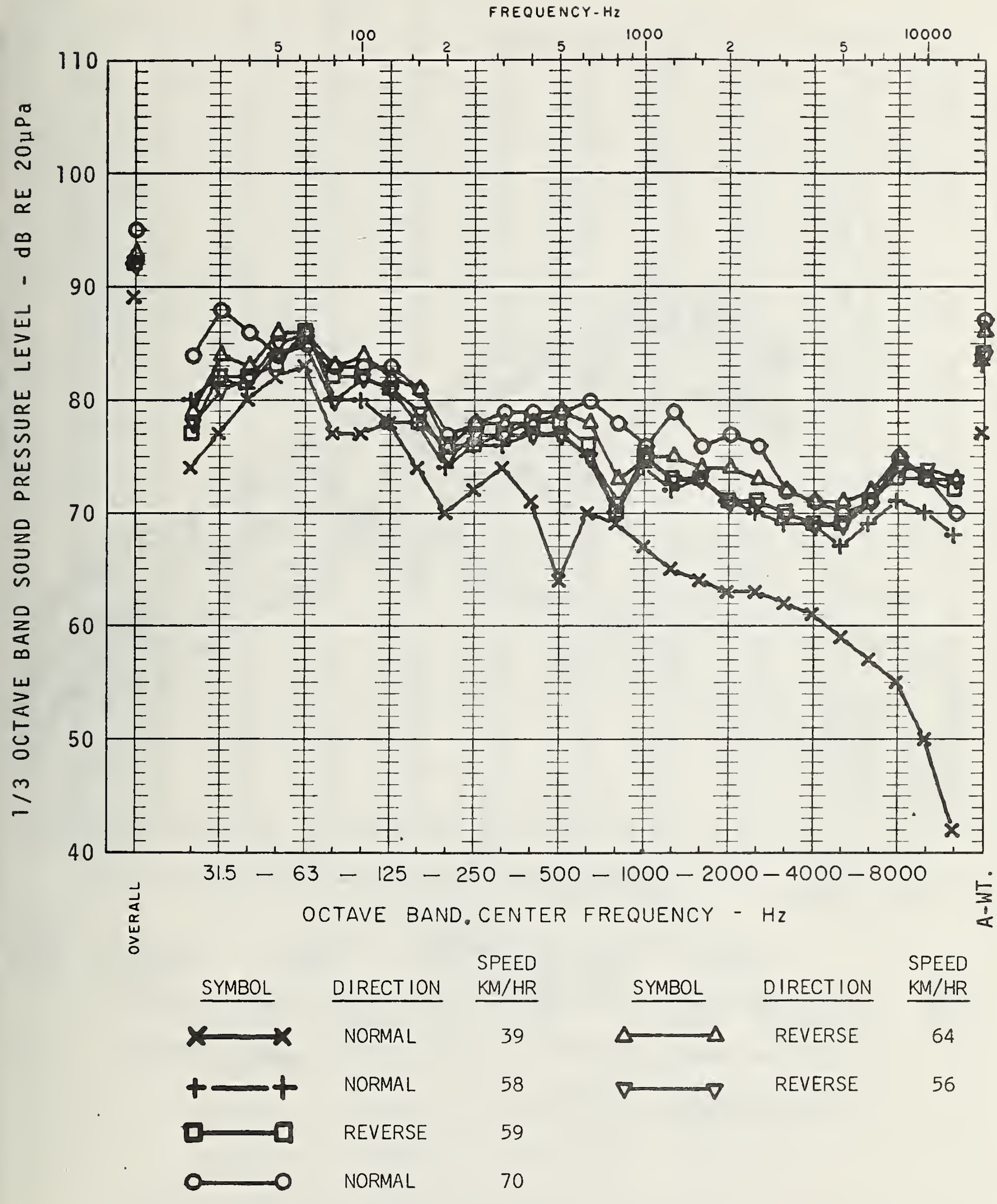


FIGURE A-18. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IC; SEPTEMBER 2, 1976

WAYSIDE - TRUED STANDARD WHEELS

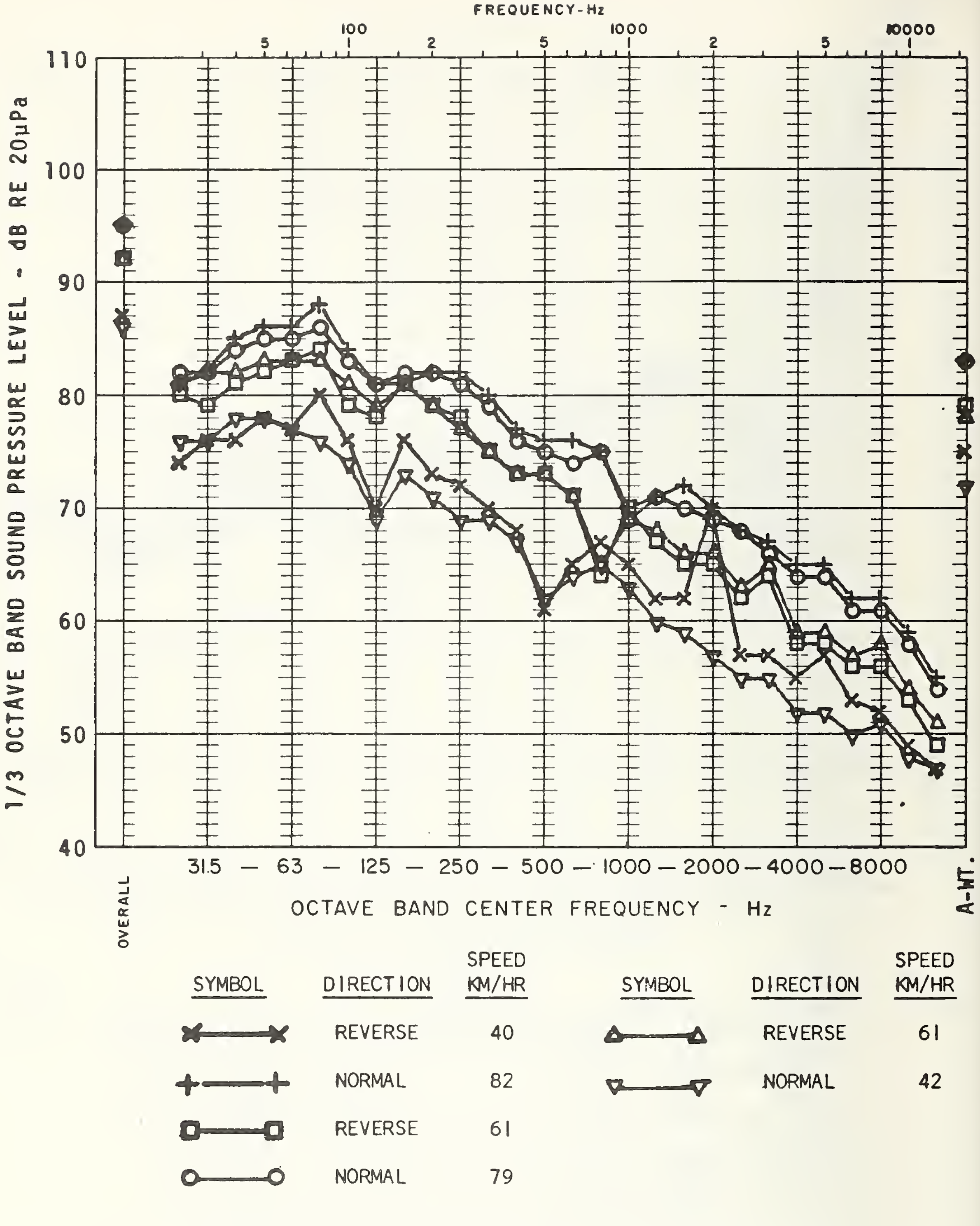
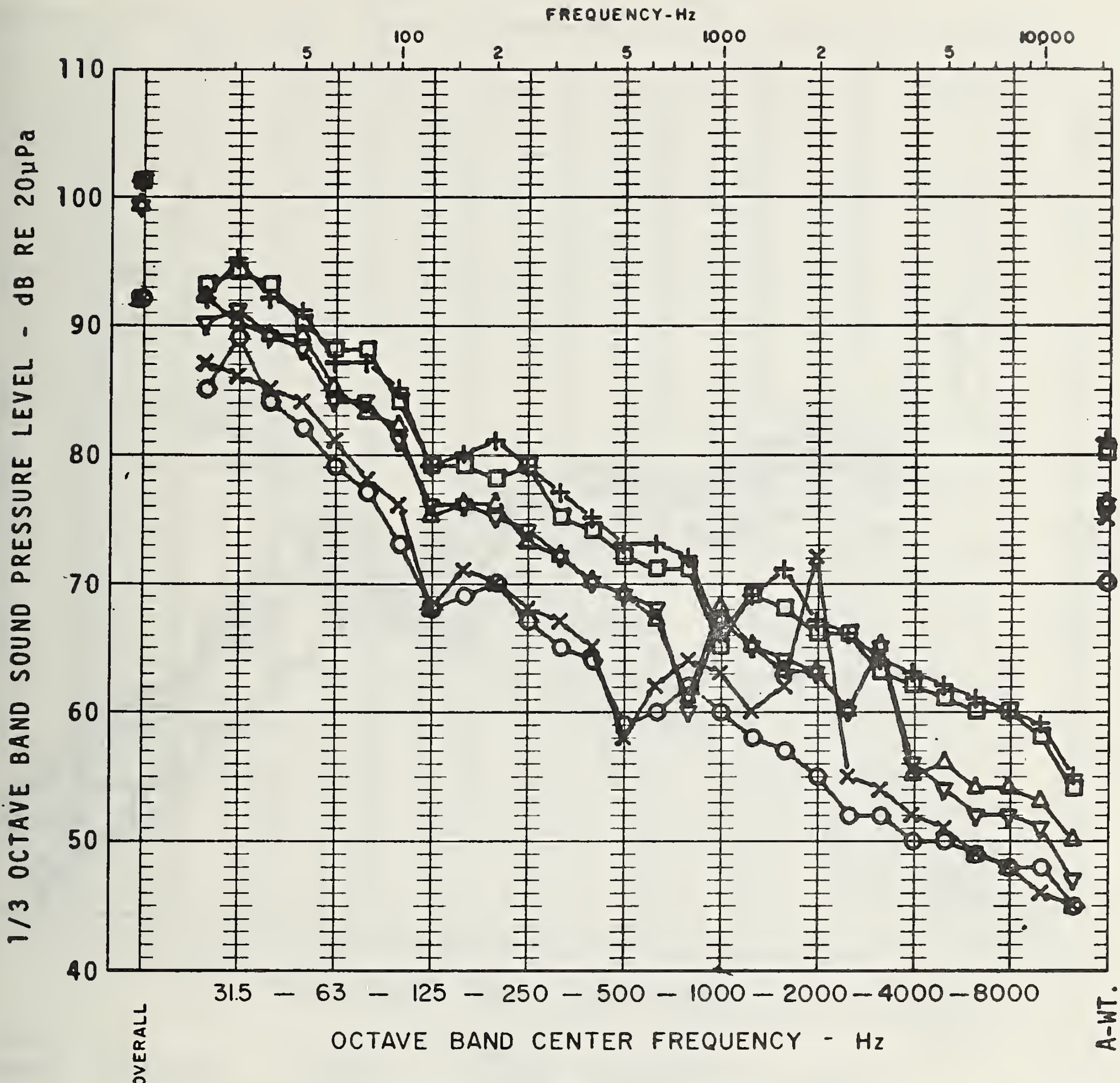


FIGURE A-19. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IIA; OCTOBER 4, 1976

CAR INTERIOR, OVER TRUCK - TRUED STANDARD WHEELS

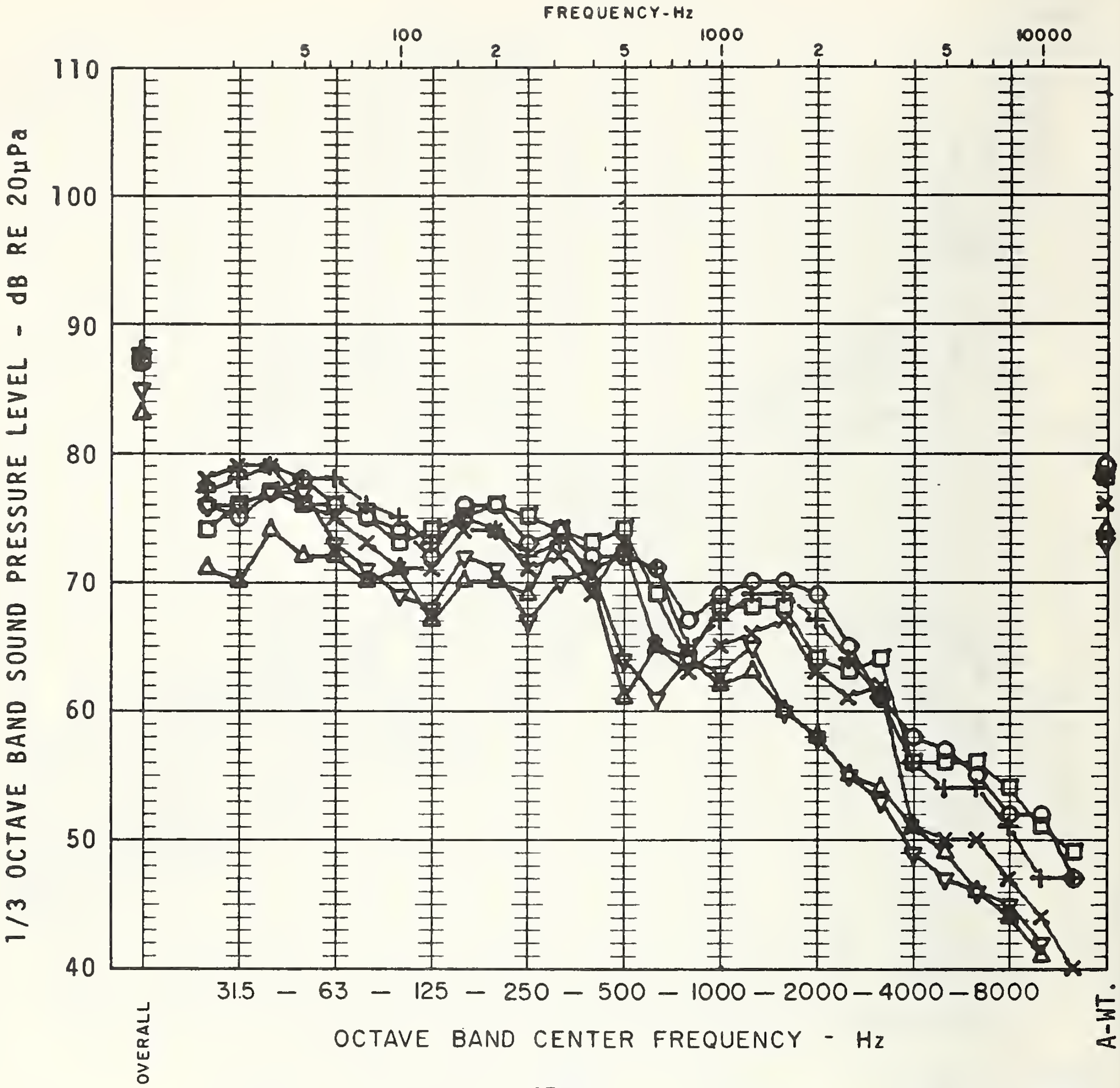


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	40	△—△	REVERSE	61
+—+	NORMAL	82	▽—▽	REVERSE	61
□—□	NORMAL	79			
○—○	NORMAL	42			

FIGURE A-20. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

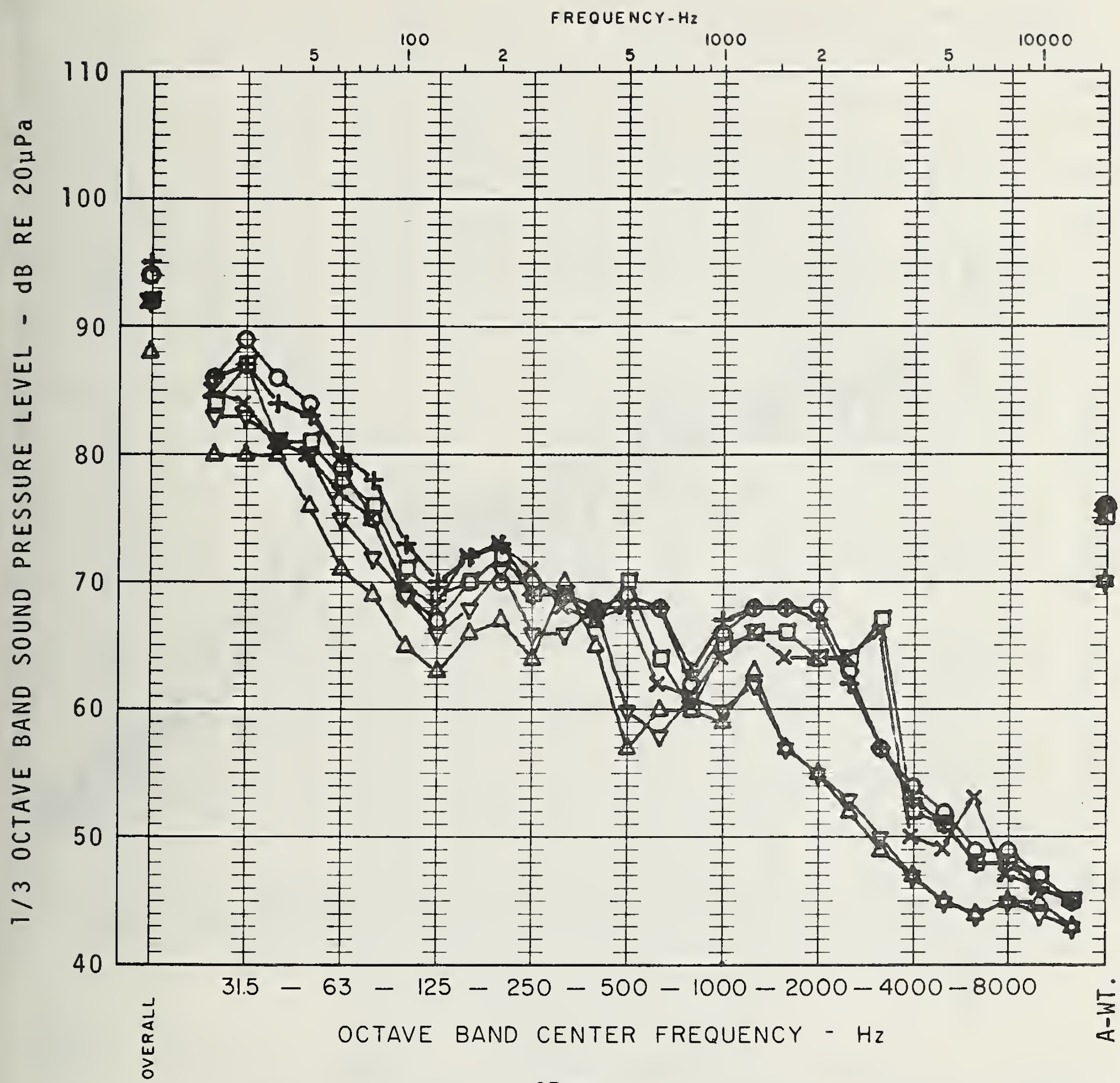
PHASE IIA; OCTOBER 4, 1976

CAR INTERIOR AT CENTER - TRUED STANDARD WHEELS



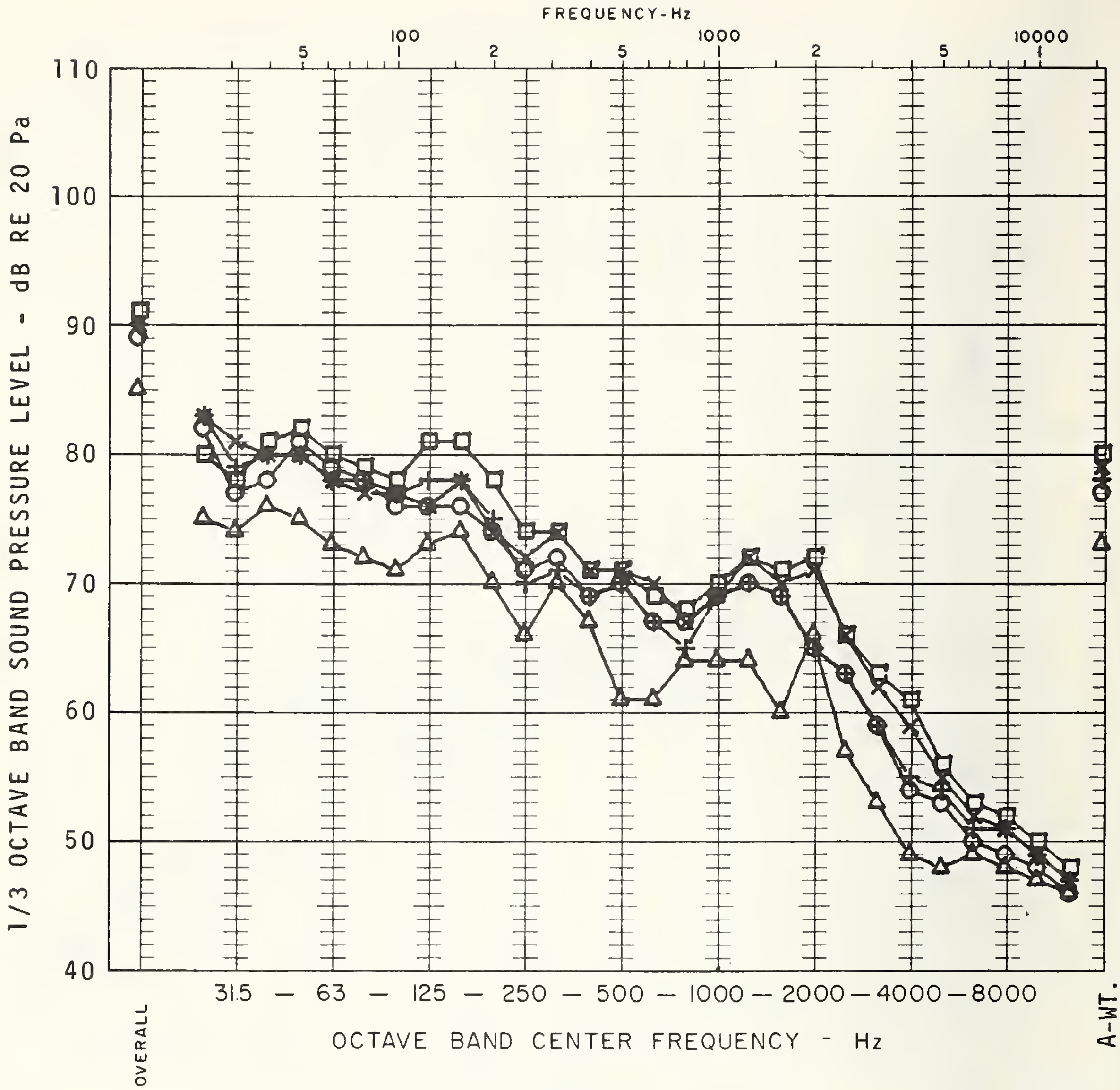
SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	54	△——△	REVERSE	39
+——+	NORMAL	67	▽——▽	NORMAL	43
□——□	REVERSE	56			
○——○	NORMAL	67			

FIGURE A-21. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR, OVER TRUCK - NEW ACOUSTAFLEX RESILIENT WHEELS



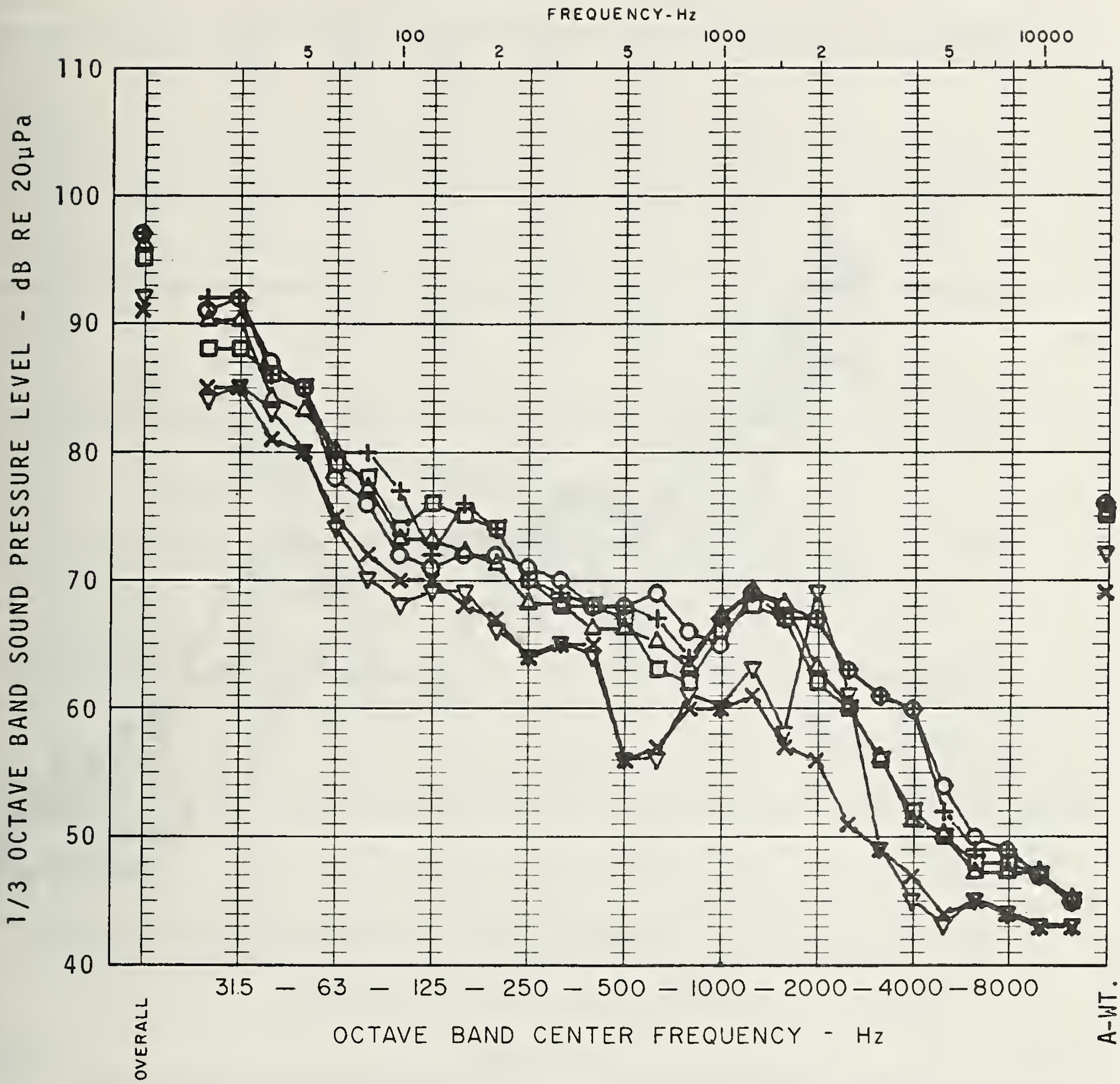
SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	54	△——△	REVERSE	39
+——+	NORMAL	67	▽——▽	NORMAL	43
□——□	REVERSE	56			
○——○	NORMAL	67			

FIGURE A-22. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR AT CENTER - NEW ACOUSTAFLEX RESILIENT WHEELS



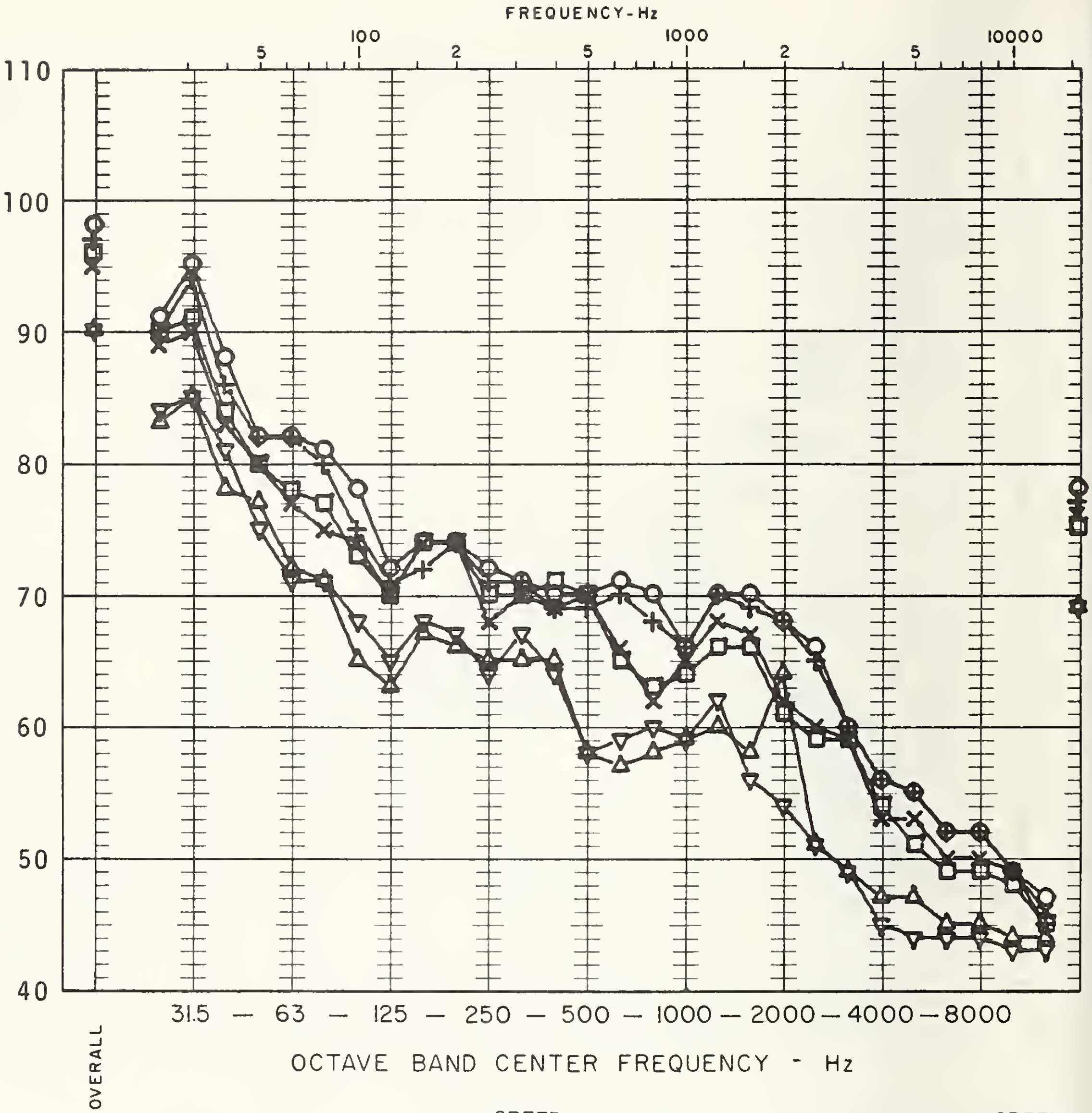
SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	NORMAL	69	○—○	REVERSE	60
+—+	REVERSE	60	△—△	NORMAL	43
□—□	NORMAL	70			

FIGURE A-23. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR, OVER TRUCK - NEW PENN BOCHUM RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR
X——X	REVERSE	42
+——+	NORMAL	69
□——□	REVERSE	60
○——○	NORMAL	70
△——△	REVERSE	60
▽——▽	NORMAL	43

FIGURE A-24. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR AT CENTER - NEW PENN BOCHUM RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×———×	REVERSE	59	△———△	REVERSE	41
+———+	NORMAL	76	▽———▽	NORMAL	41
□———□	REVERSE	59			
○———○	NORMAL	81			

FIGURE A-25. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR, OVER TRUCK - NEW SAB RESILIENT WHEELS

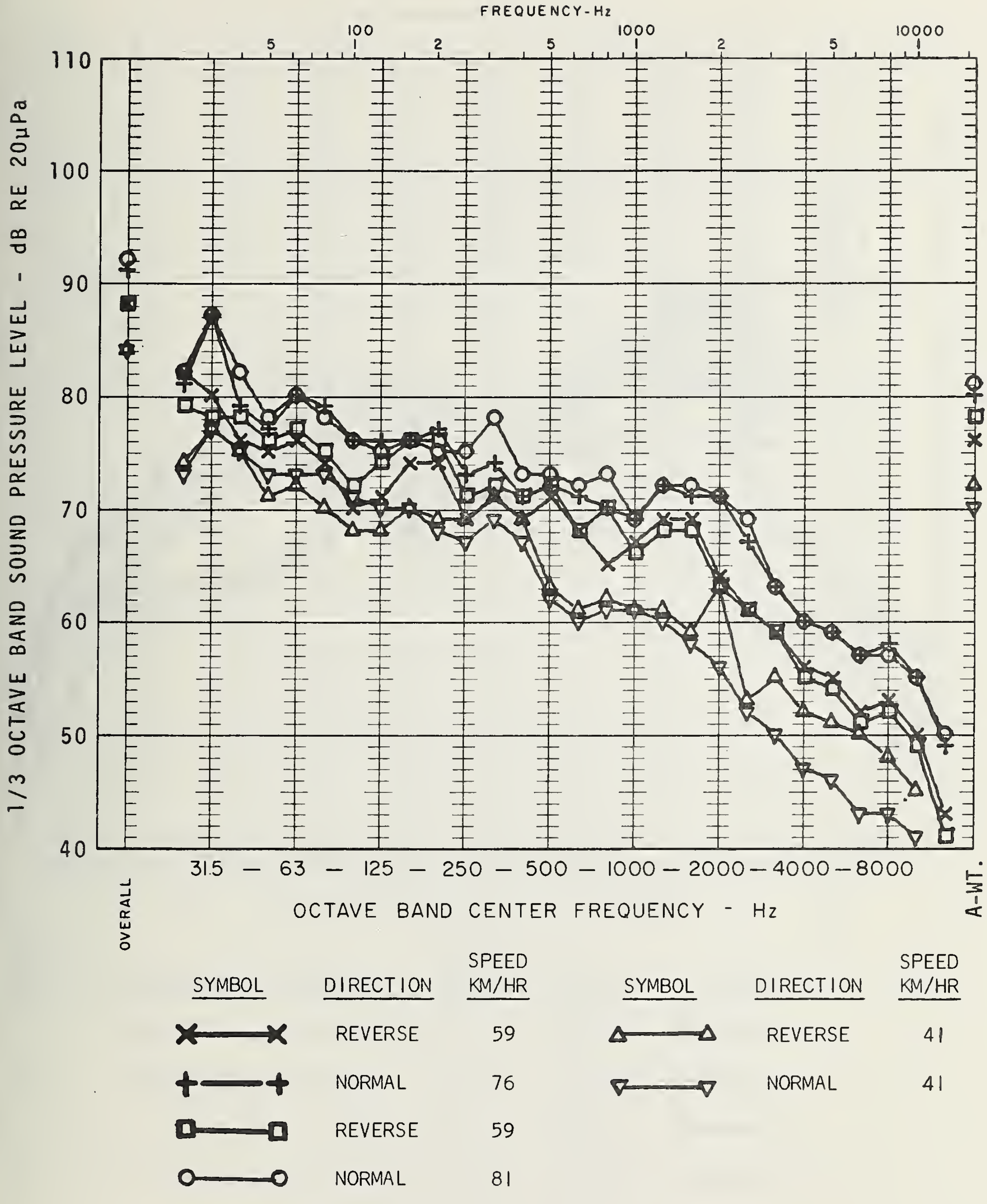
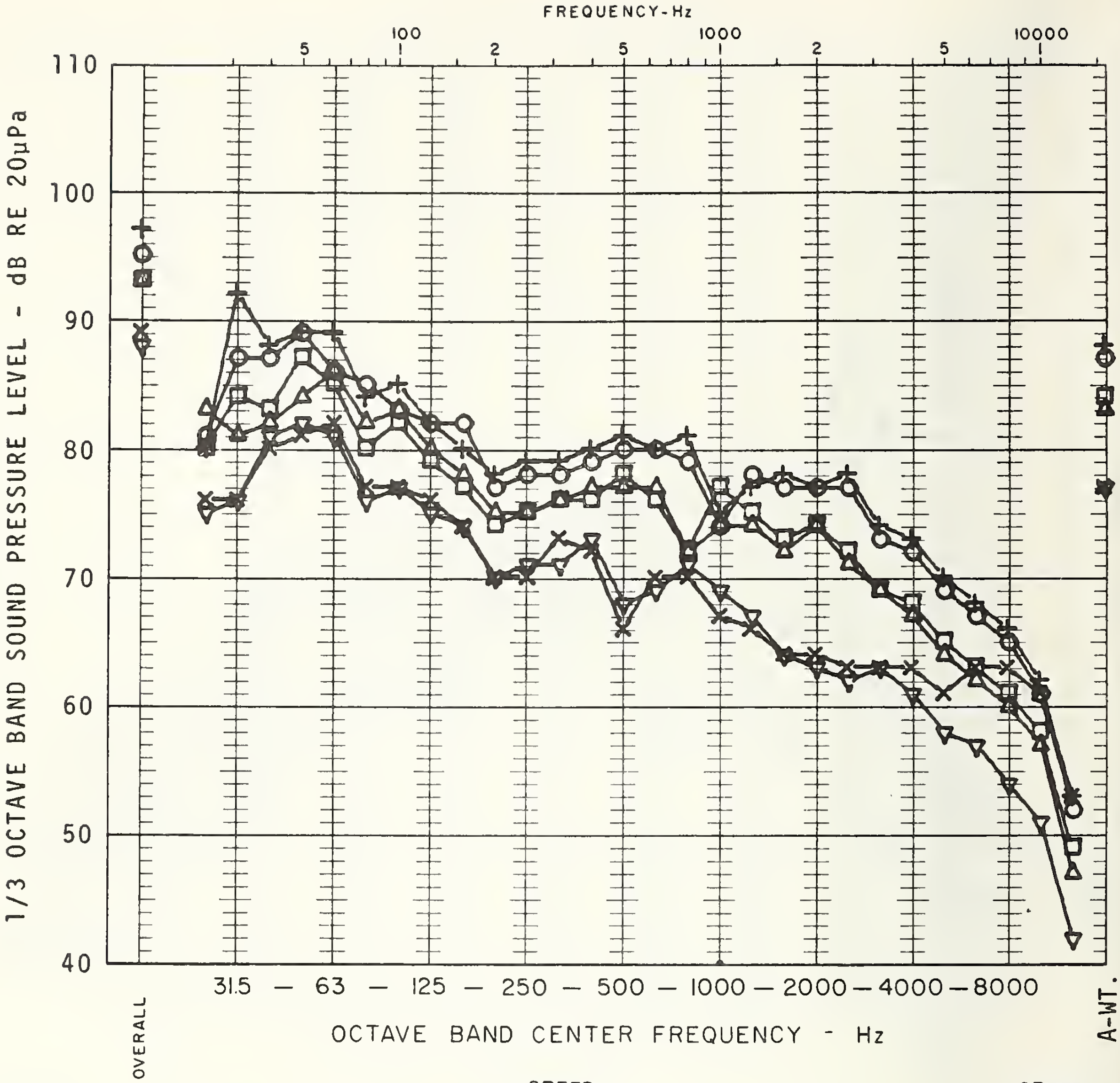


FIGURE A-26. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR AT CENTER - NEW SAB RESILIENT WHEELS

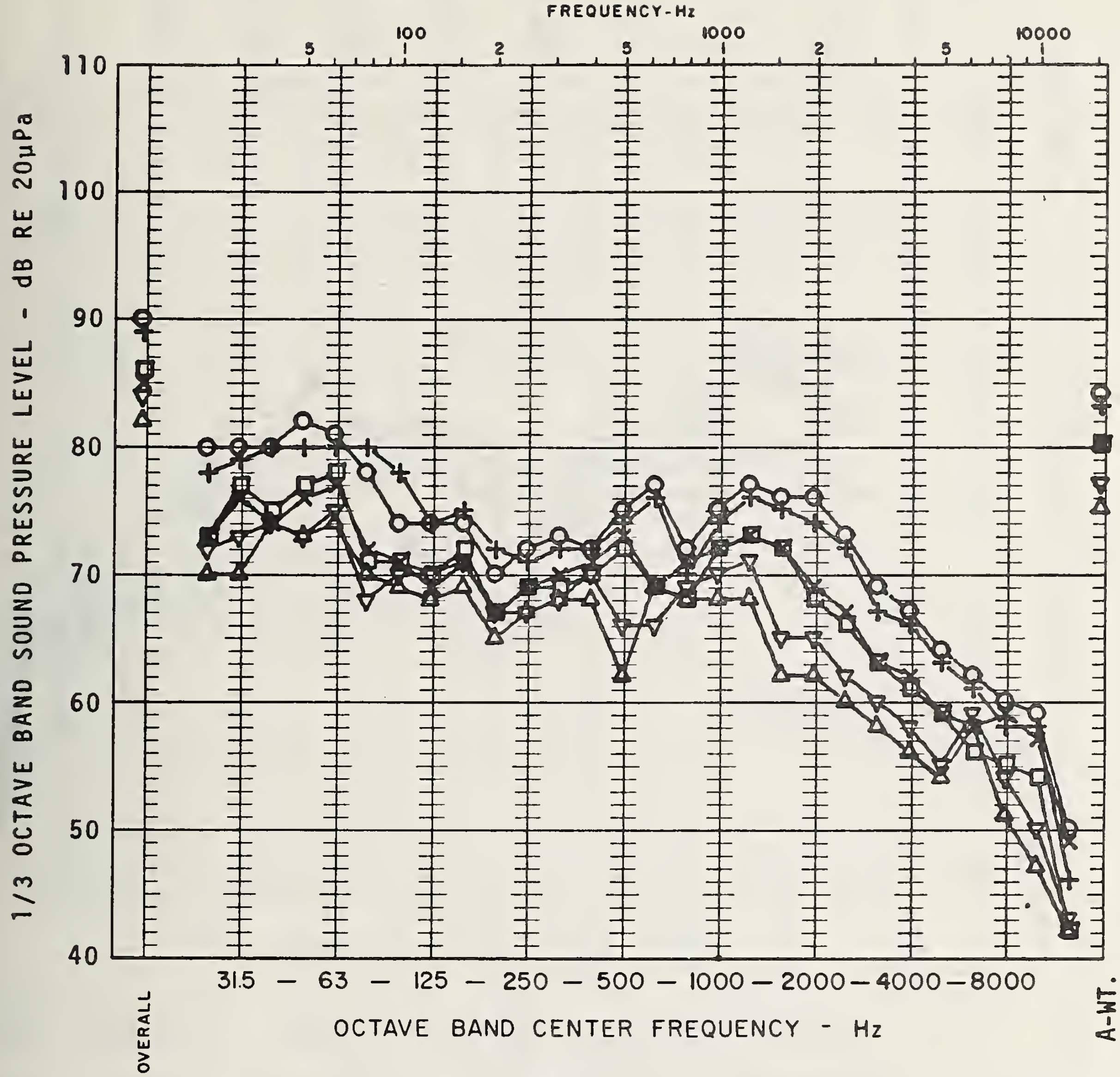


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
X——X	REVERSE	40	△——△	REVERSE	61
+——+	NORMAL	82	▽——▽	NORMAL	42
□——□	REVERSE	61			
O——O	NORMAL	79			

FIGURE A-27. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IIA; OCTOBER 4, 1976

WAYSIDE - TRUED STANDARD WHEELS

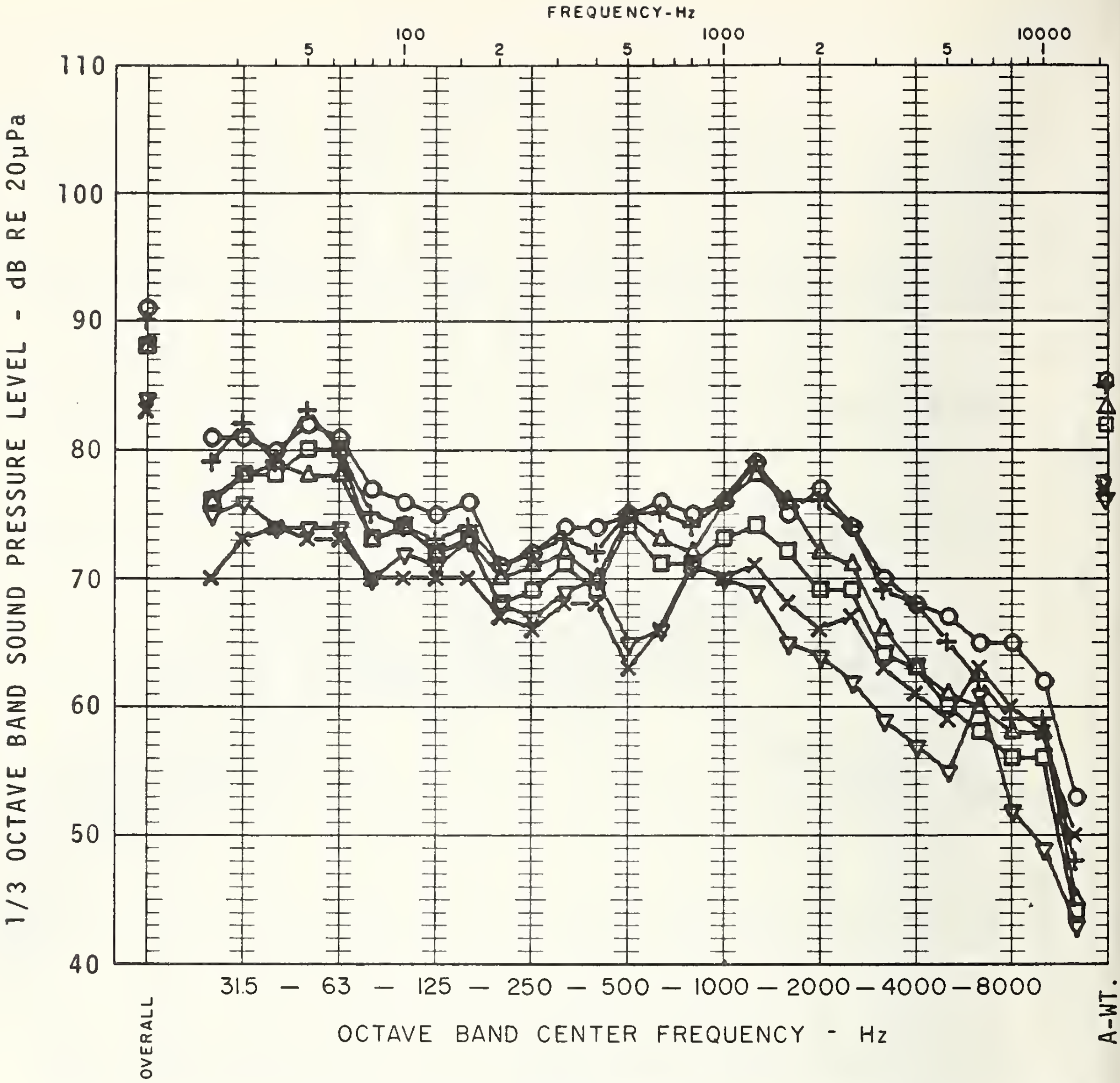


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE.	54	△——△	REVERSE	39
+——+	NORMAL	67	▽——▽	NORMAL	43
□——□	REVERSE	56			
○——○	NORMAL	67			

FIGURE A-28. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IIA; OCTOBER 4, 1976

WAYSIDE - NEW ACOUSTAFLEX RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	42	△—△	REVERSE	60
+—+	NORMAL	69	▽—▽	NORMAL	43
□—□	REVERSE	60			
○—○	NORMAL	70			

FIGURE A-29. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

PHASE IIA; OCTOBER 4, 1976

WAYSIDE - NEW PENN BOCHUM RESILIENT WHEELS

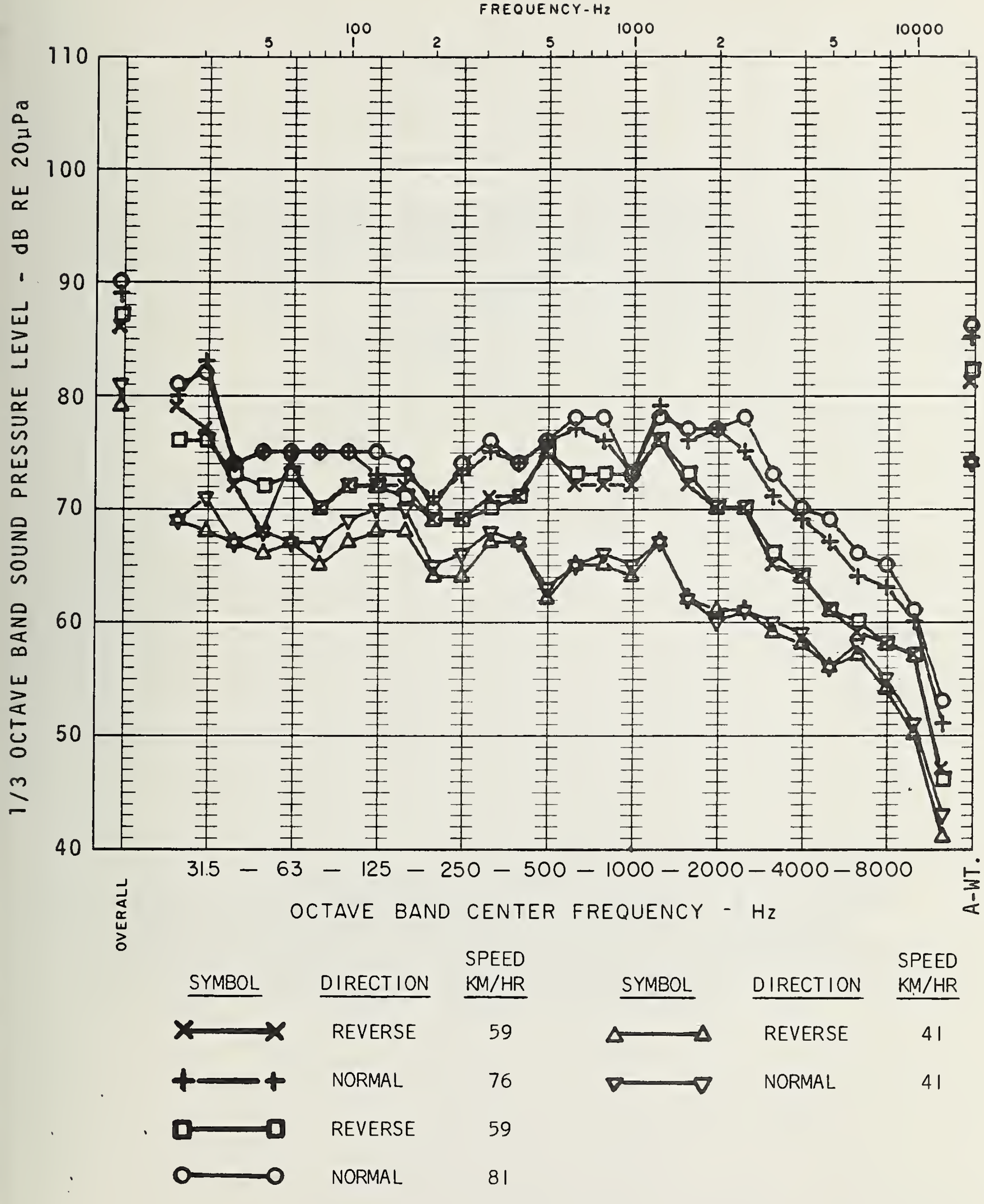


FIGURE A-30. TANGENT-WELDED BALLAST AND TIE TEST TRACK [TW]

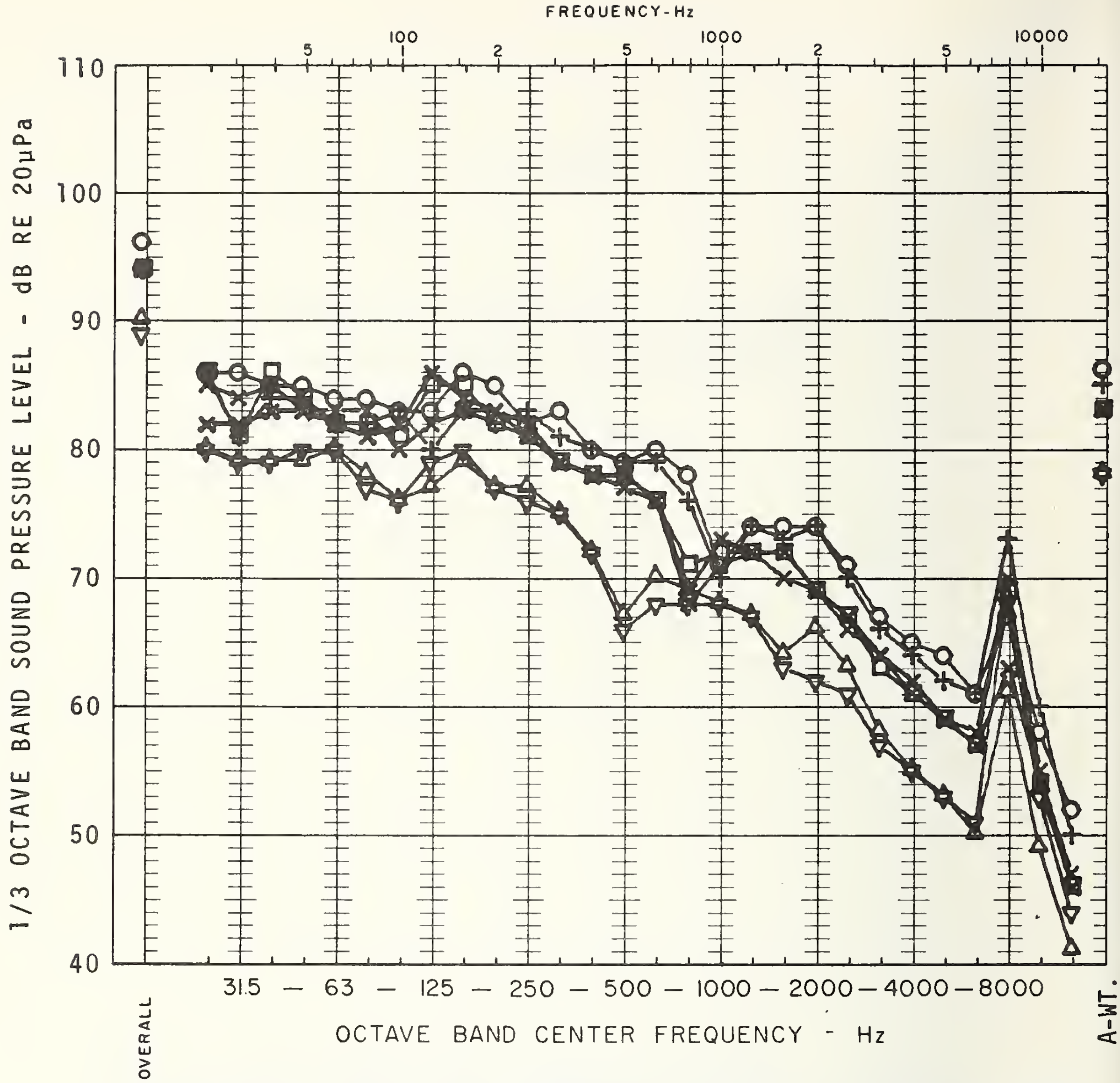
PHASE IIA; OCTOBER 4, 1976

WAYSIDE - NEW SAB RESILIENT WHEELS

APPENDIX B

SPECTRA OF MEASUREMENTS ON TANGENT JOINTED BALLAST AND TIE TRACK*- TEST TRACK A

* Spectra include wayside and car interior measurements for worn-standard and new-standard wheels for Test Phases IA & IB; wayside and car interior measurements for trued-standard, Acoustaflex, Bochum and SAB wheels for Test Phases IIA & IIB; and wayside and car interior measurements for worn-standard wheels for Test Phase IIB. Notch filter used on all spectra in Appendix B.



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	NORMAL	60	△——△	NORMAL	40
+——+	REVERSE	76	▽——▽	REVERSE	40
□——□	NORMAL	58	×——×	NORMAL	60
○——○	REVERSE	78			

FIGURE B-1. BALLAST AND TIE TANGENT JOINTED-TEST TRACK A
PHASE IA; JULY 14, 1976
CAR INTERIOR, OVER TRUCK - WORN STANDARD WHEELS

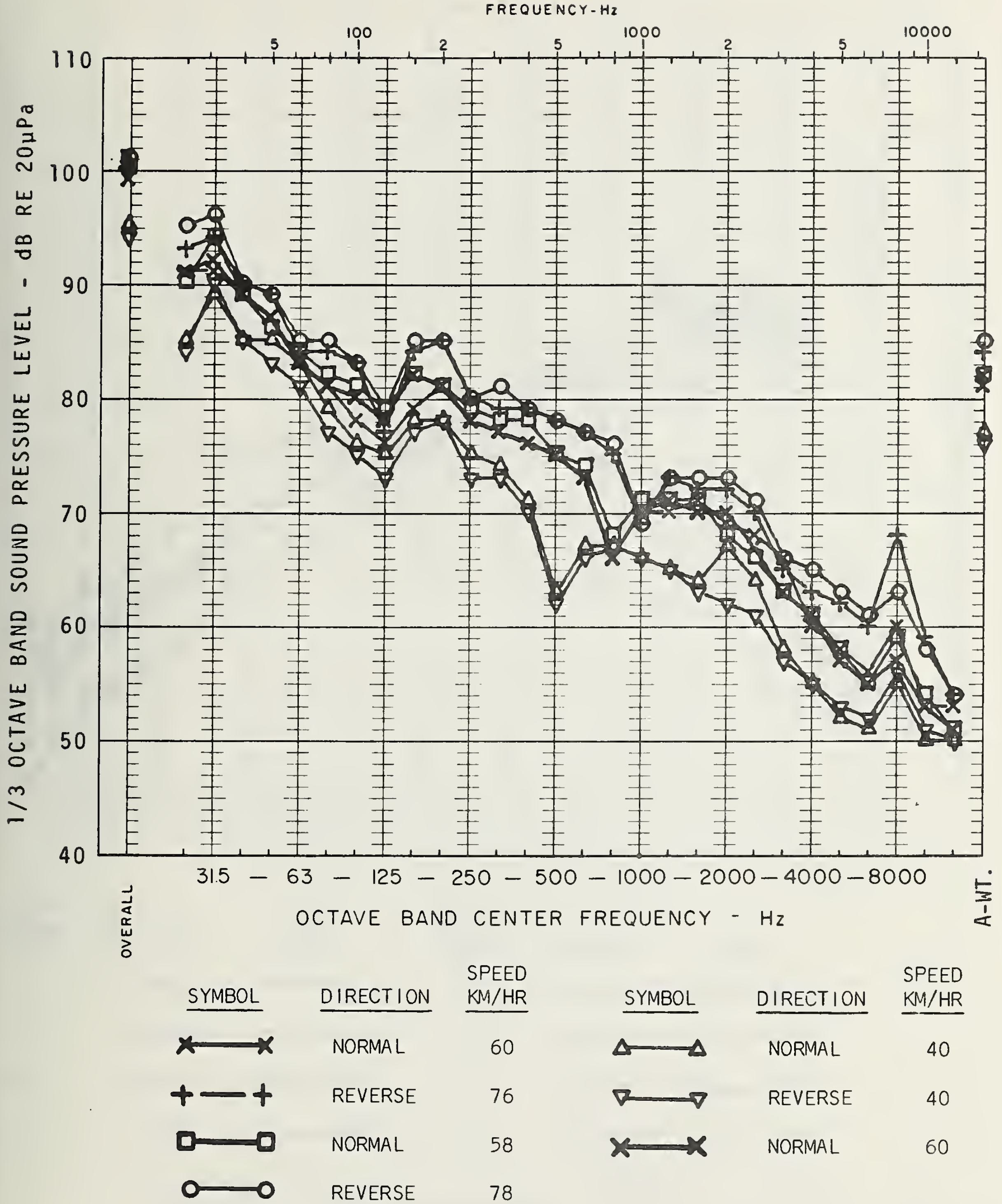
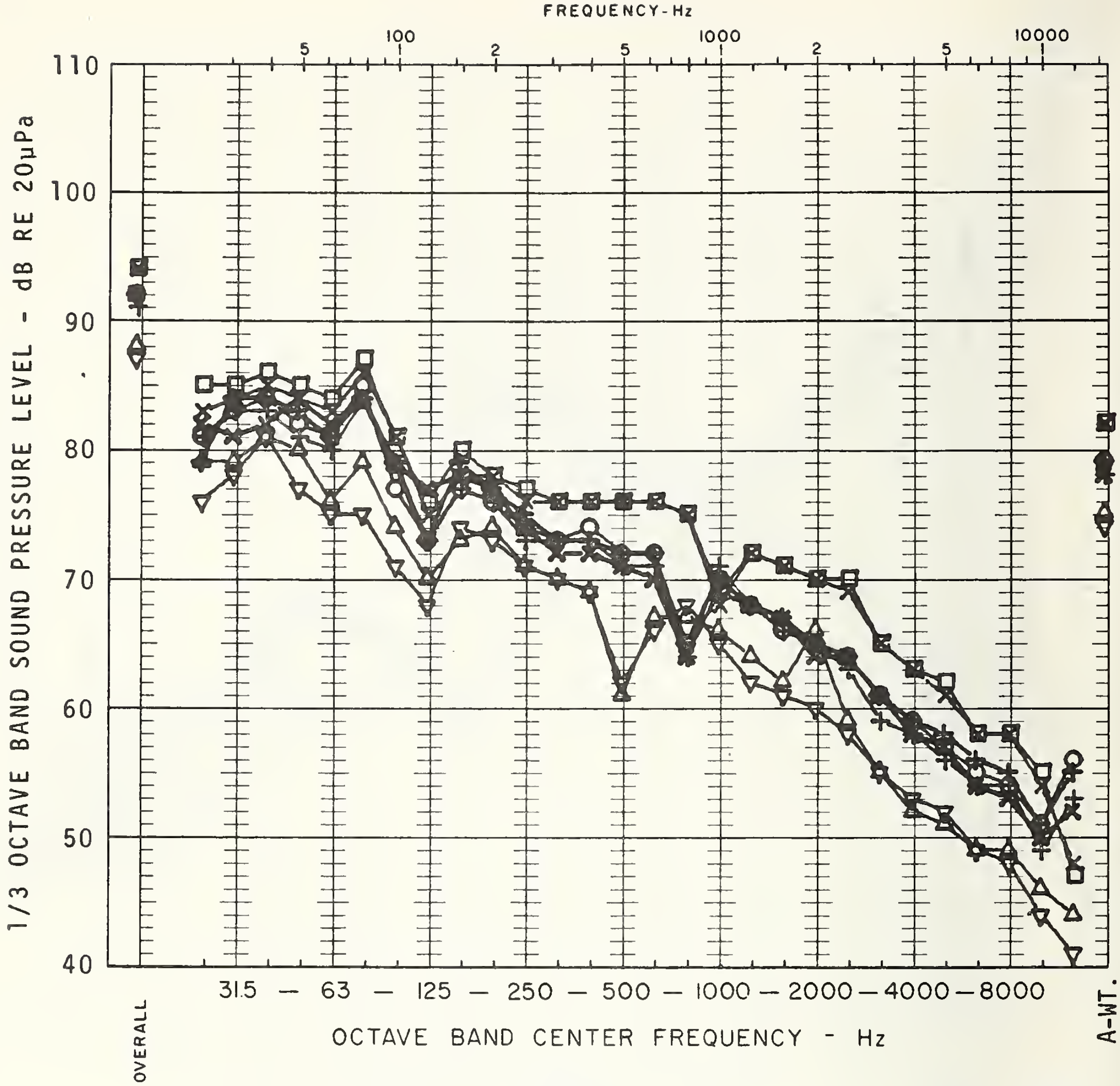


FIGURE B-2. BALLAST AND TIE TANGENT JOINTED-TEST TRACK A

PHASE IA; JULY 14, 1976

CAR INTERIOR AT CENTER - WORN STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	82	△—△	REVERSE	41
+—+	NORMAL	60	▽—▽	NORMAL	40
□—□	REVERSE	83	×—×	REVERSE	59
○—○	NORMAL	61	+—+	NORMAL	60

FIGURE B-3. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IA; JULY 14, 1976

CAR INTERIOR, OVER TRUCK - NEW STANDARD WHEELS

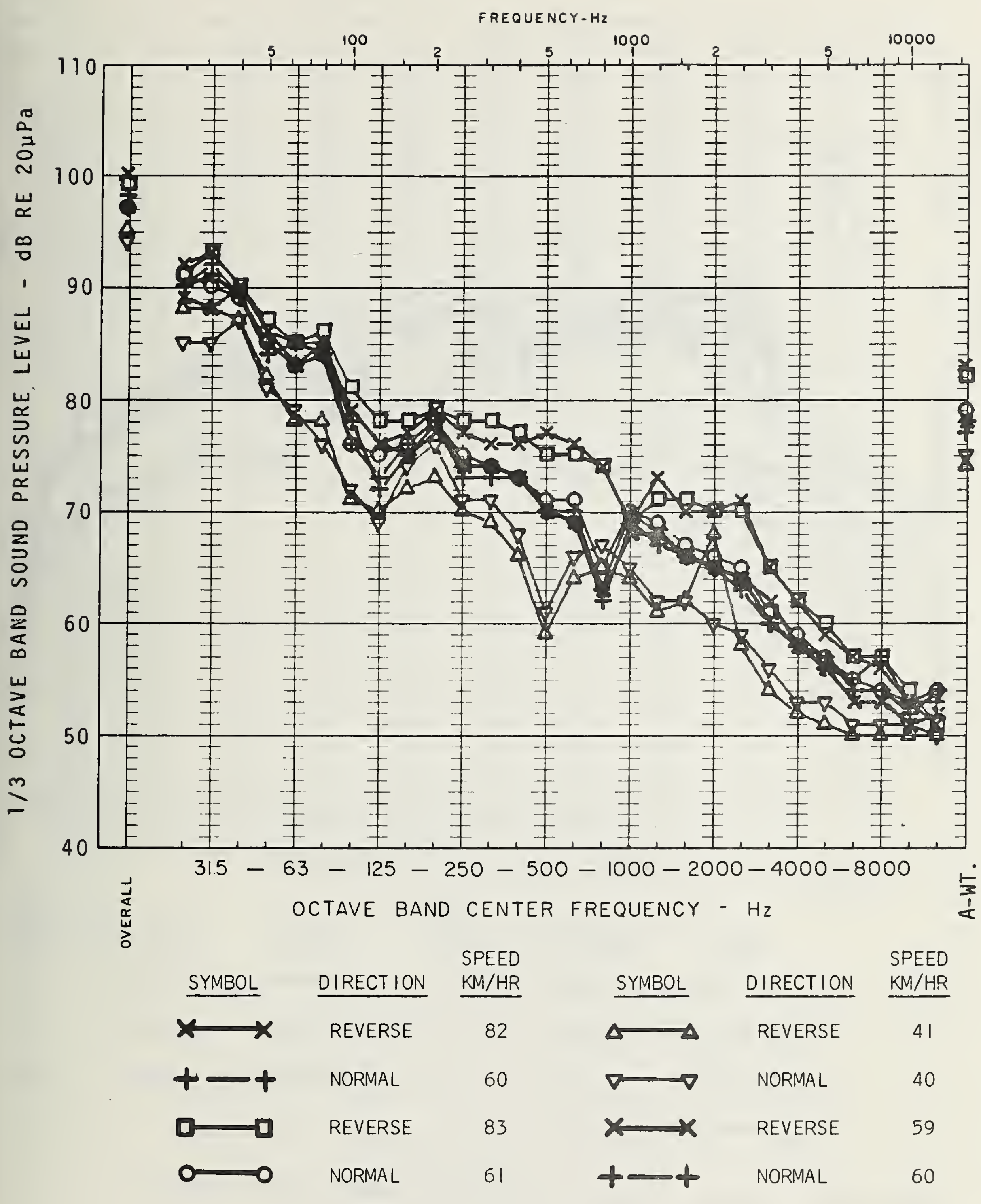
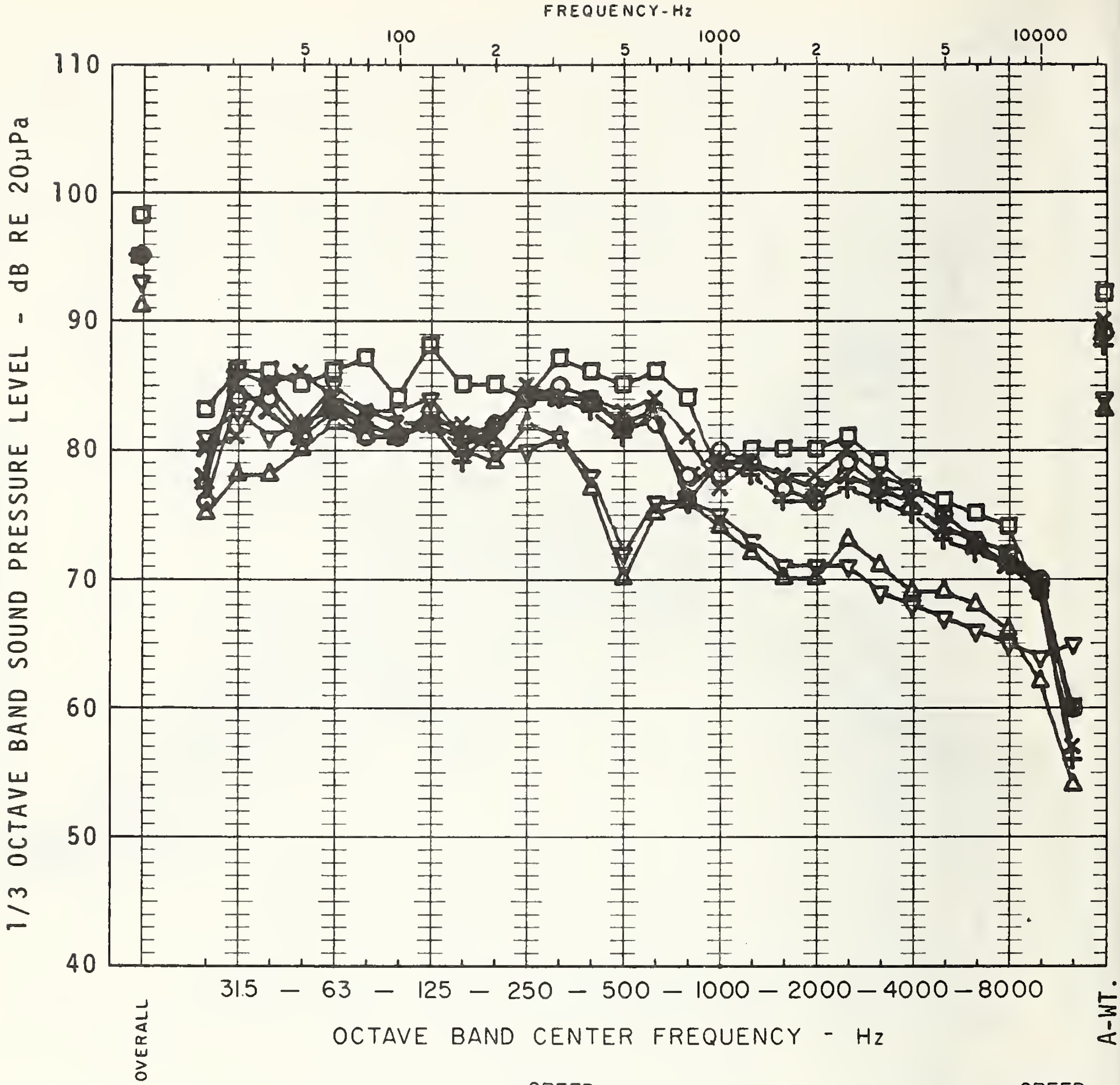


FIGURE B-4. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IA; JULY 14, 1976

CAR INTERIOR AT CENTER - NEW STANDARD WHEELS

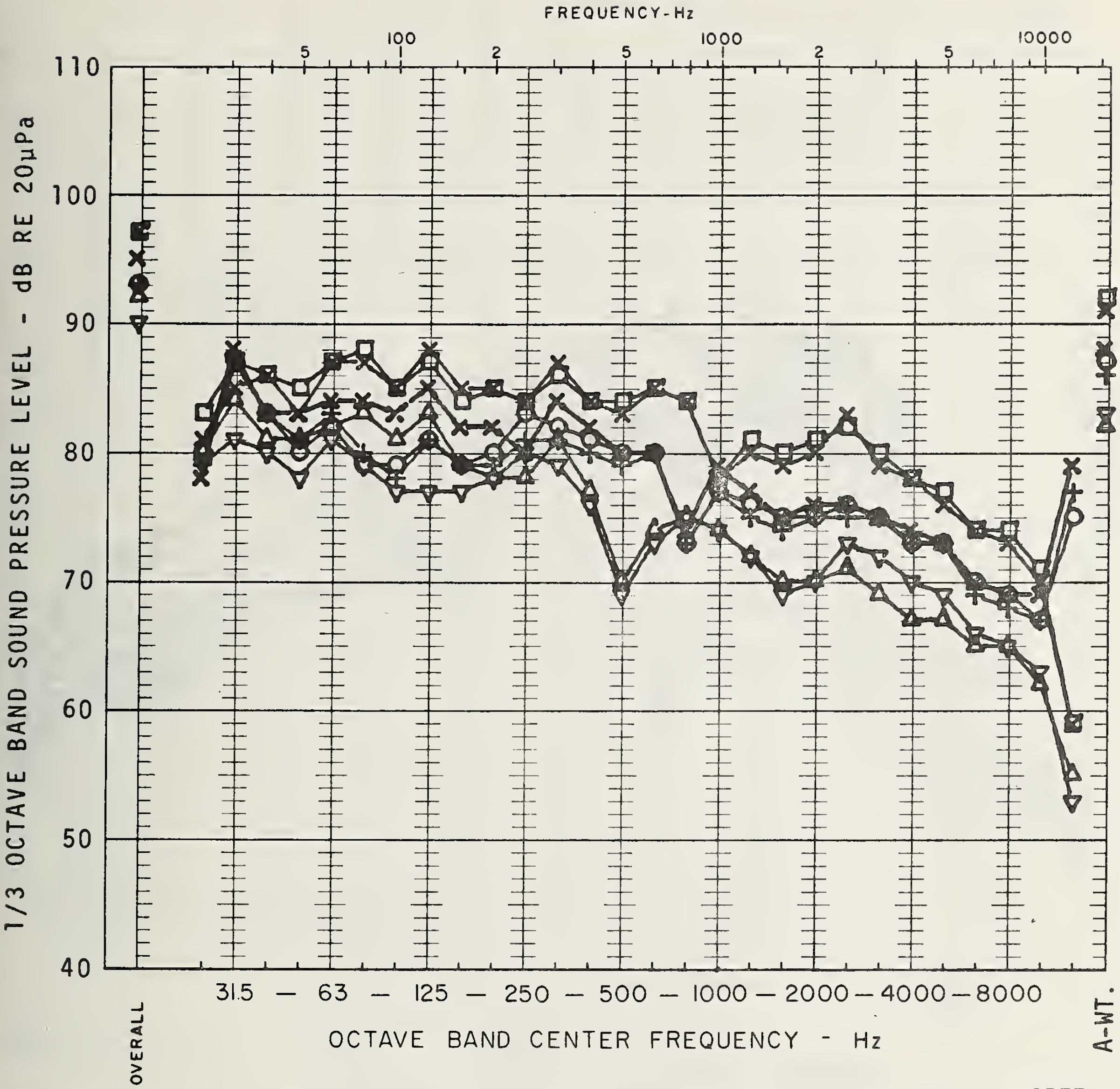


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	NORMAL	68	△—△	NORMAL	40
+—+	NORMAL	60	▽—▽	REVERSE	40
□—□	REVERSE	76	×—×	NORMAL	60
○—○	NORMAL	58			

FIGURE B-5. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

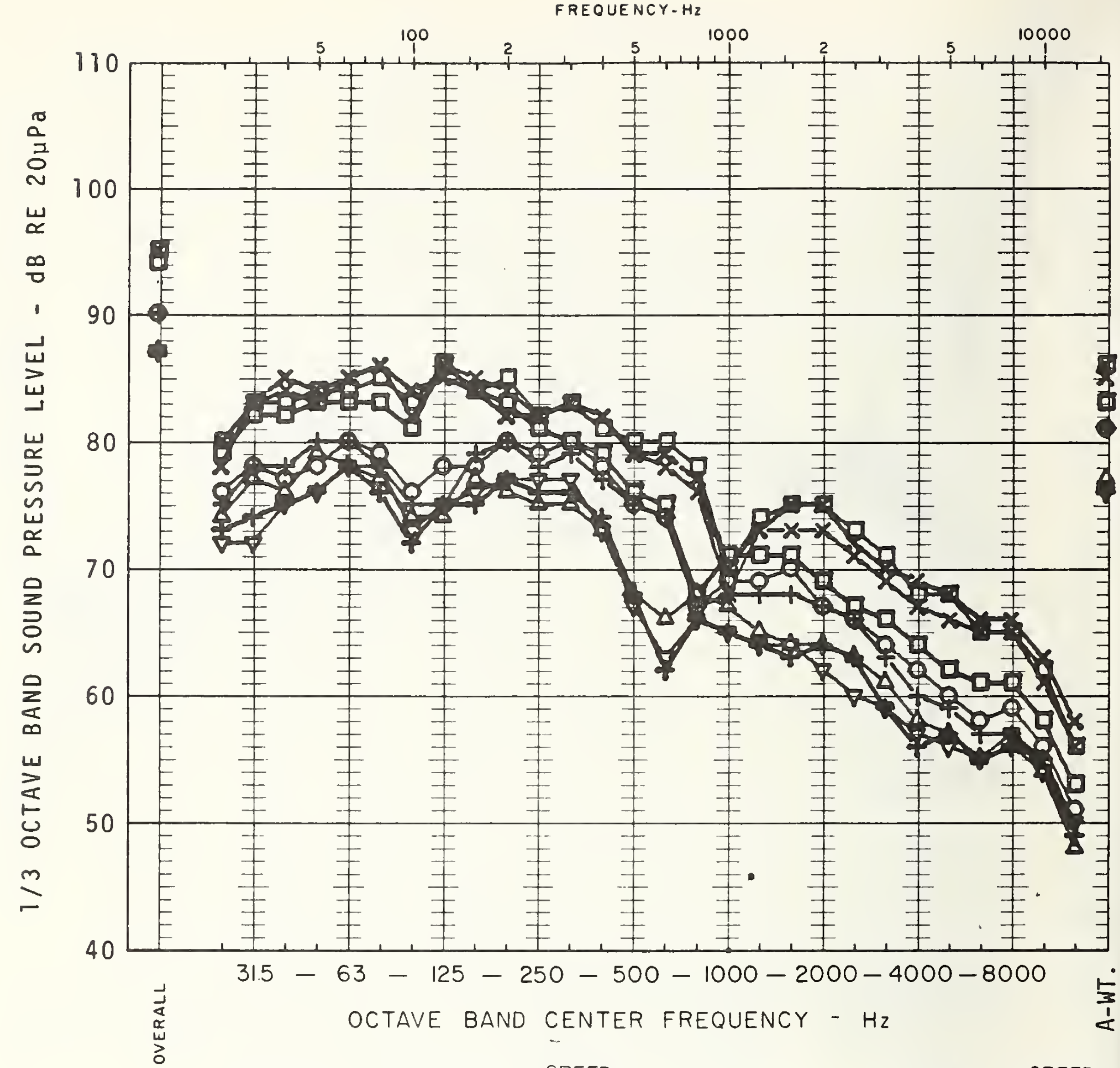
PHASE IA; JULY 14, 1976

WAYSIDE - WORN STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR
X——X	REVERSE	82
+——+	NORMAL	60
□——□	REVERSE	83
O——O	NORMAL	61
△——△	NORMAL	41
▽——▽	REVERSE	40
×——×	NORMAL	59

FIGURE B-6. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IA; JULY 14, 1976
WAYSIDE - NEW STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	76	△——△	REVERSE	45
+——+	NORMAL	61	▽——▽	NORMAL	45
□——□	REVERSE	78	×——×	REVERSE	78
○——○	NORMAL	60	+——+	NORMAL	46
			□——□	REVERSE	64

FIGURE B-8. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IB; AUGUST 17, 1976

CAR INTERIOR, OVER TRUCK - WORN STANDARD WHEELS

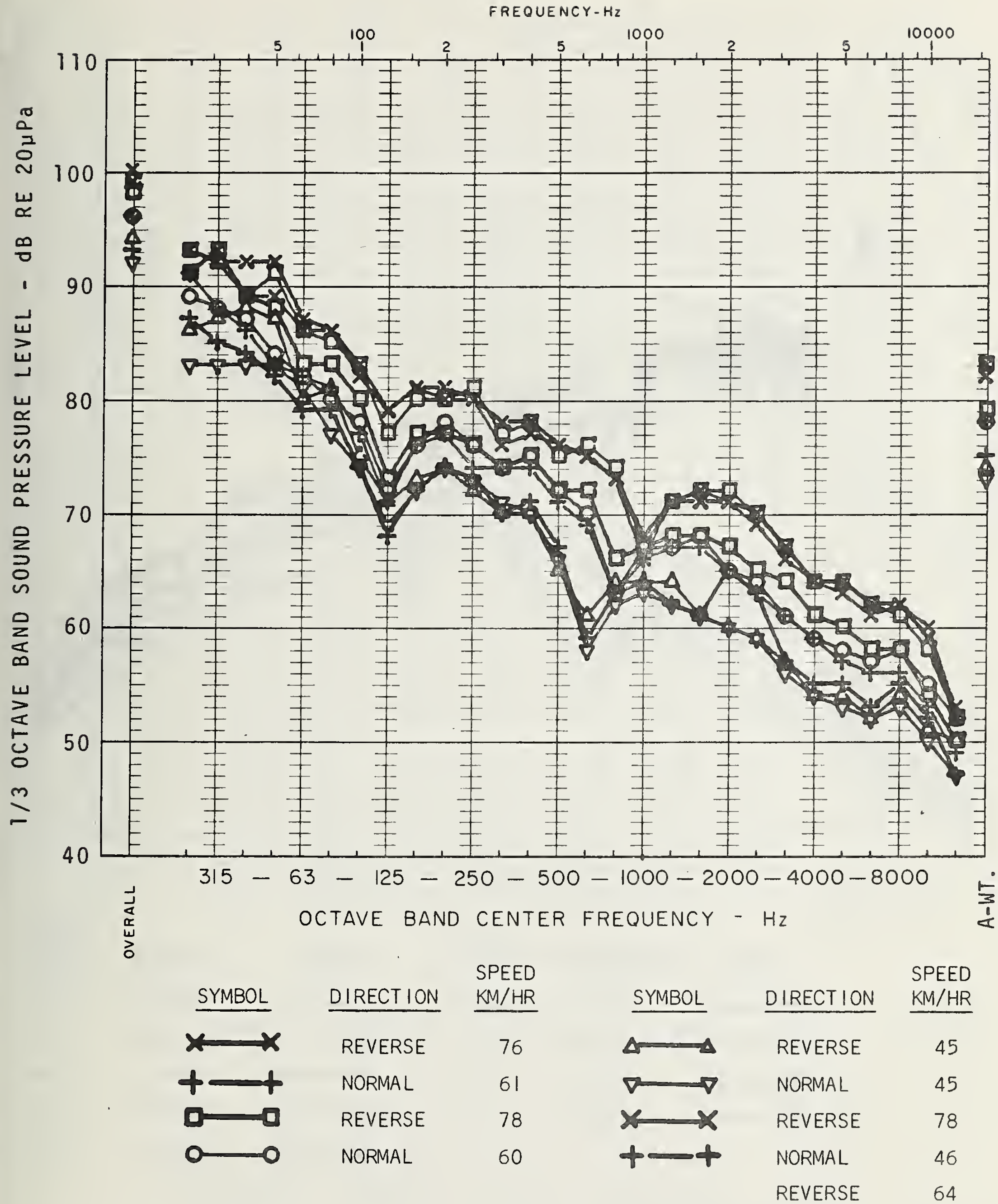
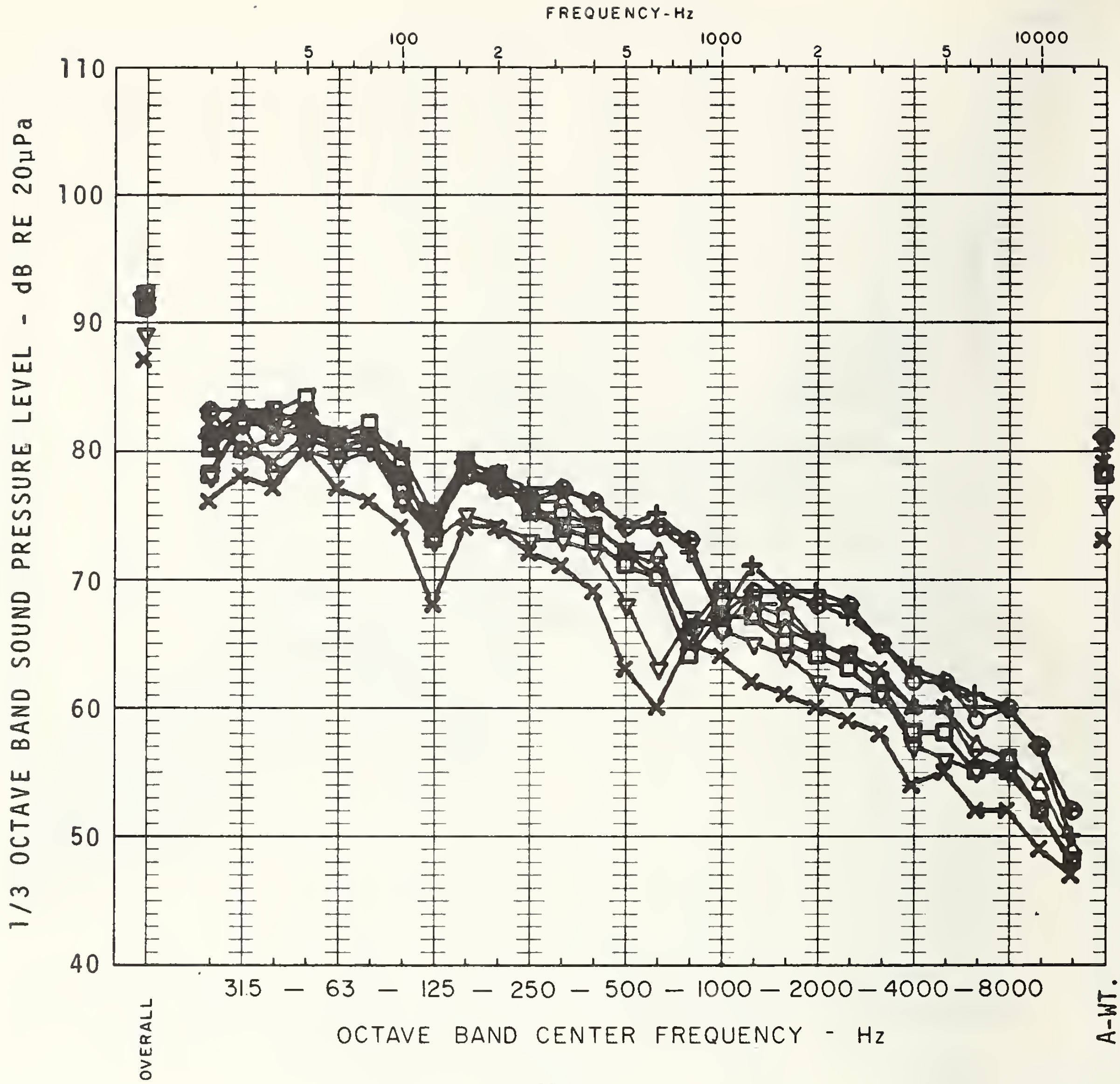


FIGURE B-7. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IB; AUGUST 17, 1976

CAR INTERIOR AT CENTER - WORN STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	NORMAL	63	△——△	NORMAL	65
+——+	REVERSE	72	▽——▽	REVERSE	50
□——□	NORMAL	64	×——×	NORMAL	44
○——○	REVERSE	73	+——+	REVERSE	74
			□——□	NORMAL	62

FIGURE B-9. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IB; AUGUST 17, 1976

CAR INTERIOR, OVER TRUCK - NEW STANDARD WHEELS

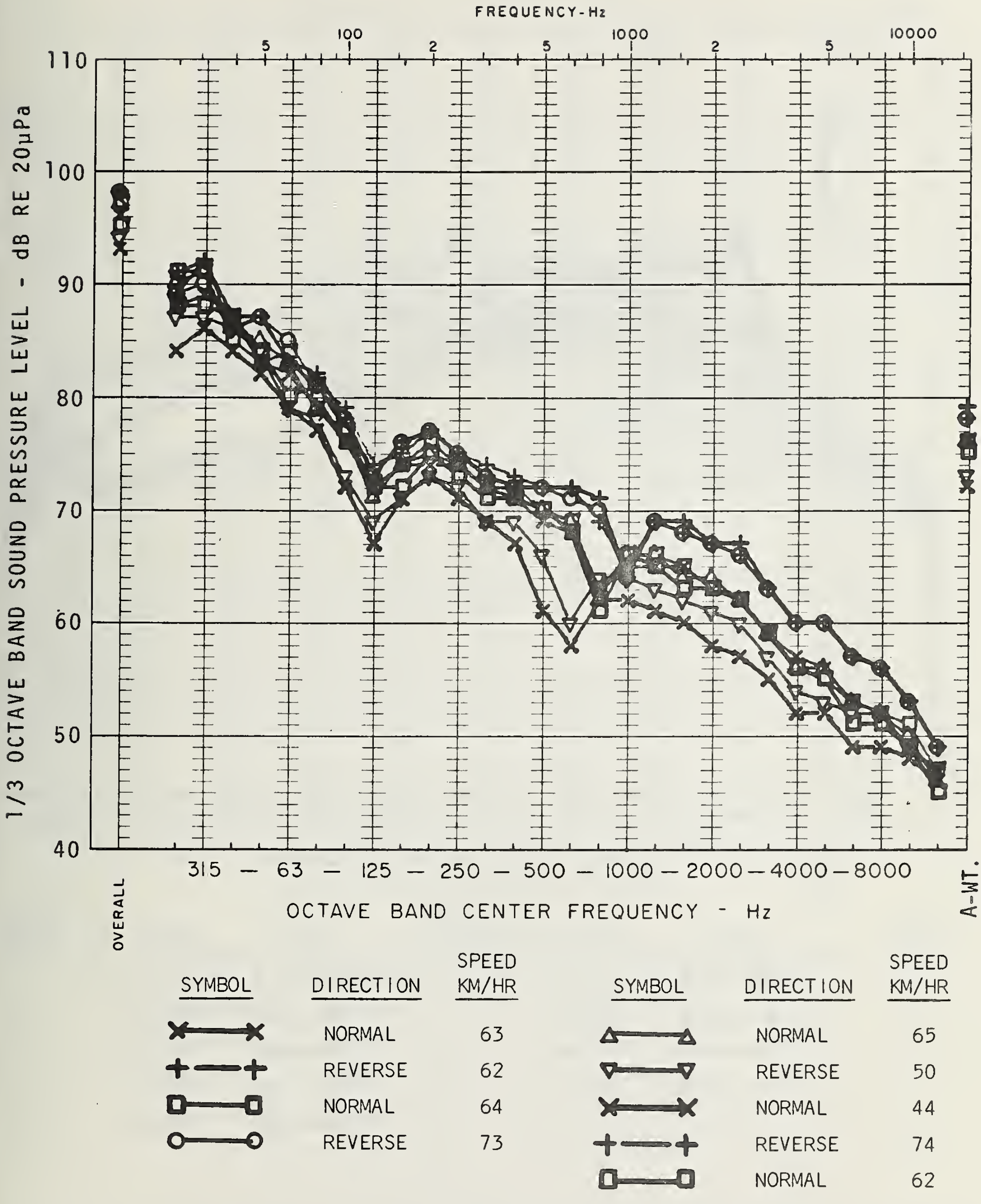


FIGURE B-10. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IB; AUGUST 17, 1976

CAR INTERIOR AT CENTER - NEW STANDARD WHEELS

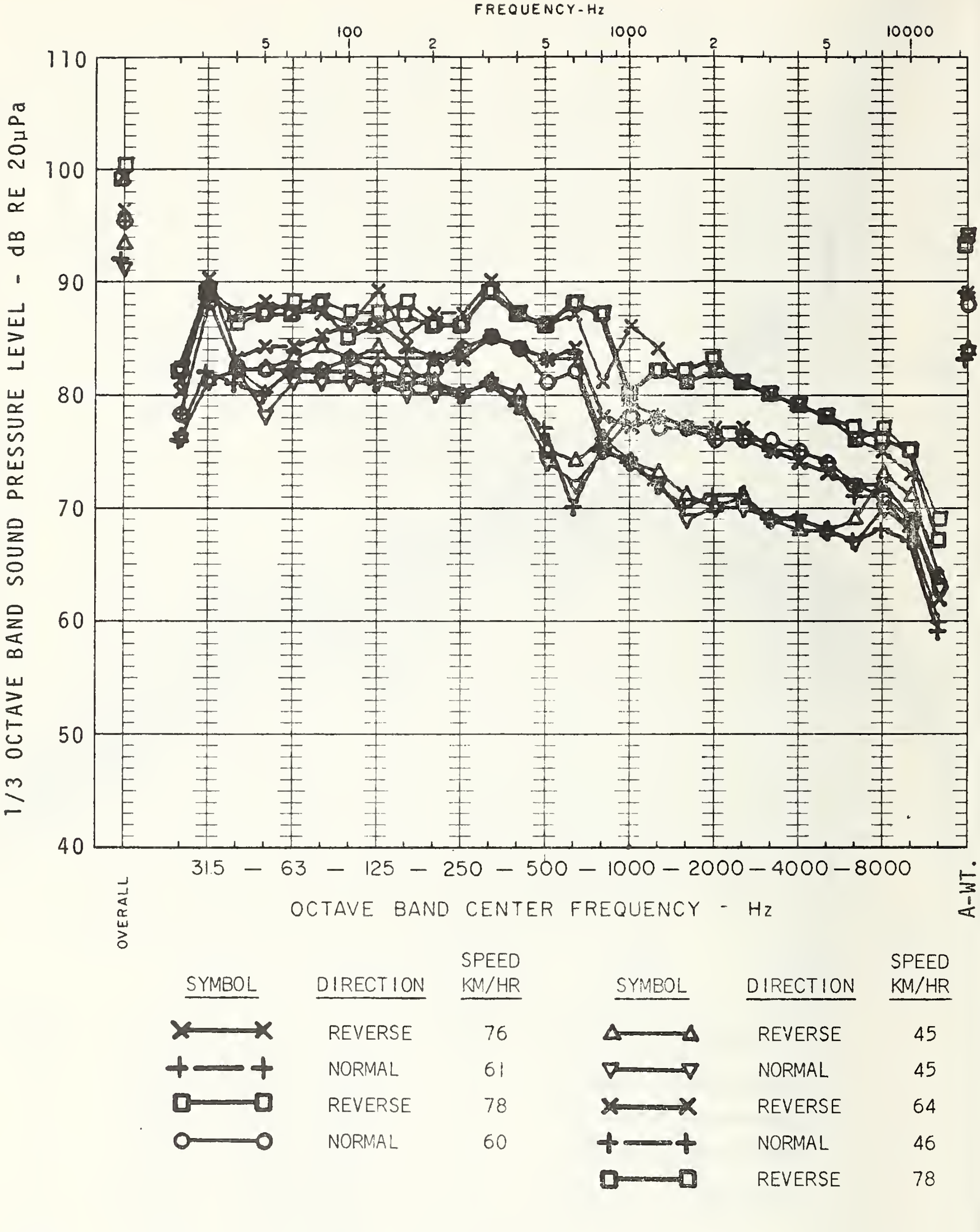
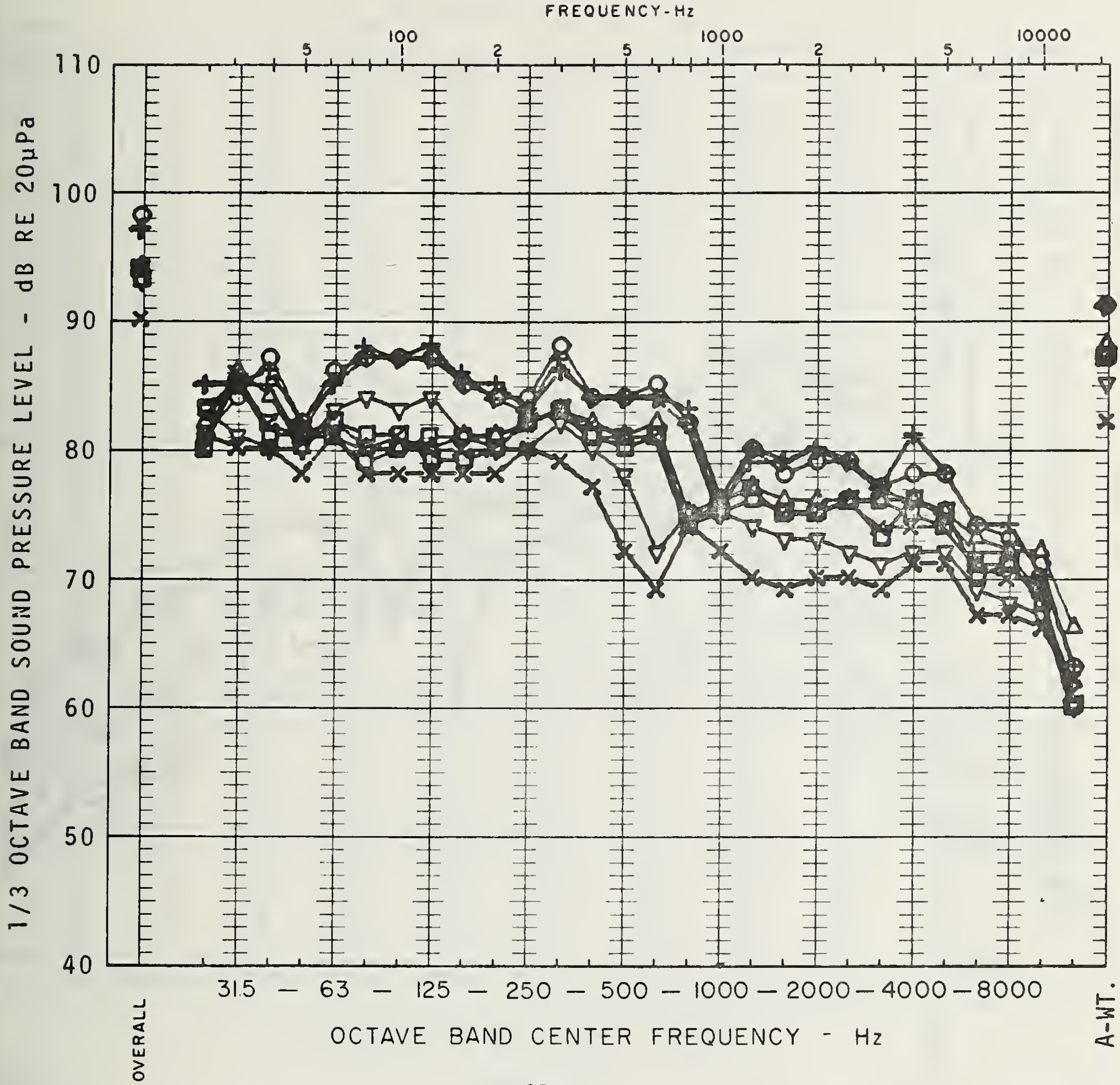


FIGURE B-11. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IB; AUGUST 17, 1976

WAYSIDE - WORN STANDARD WHEELS

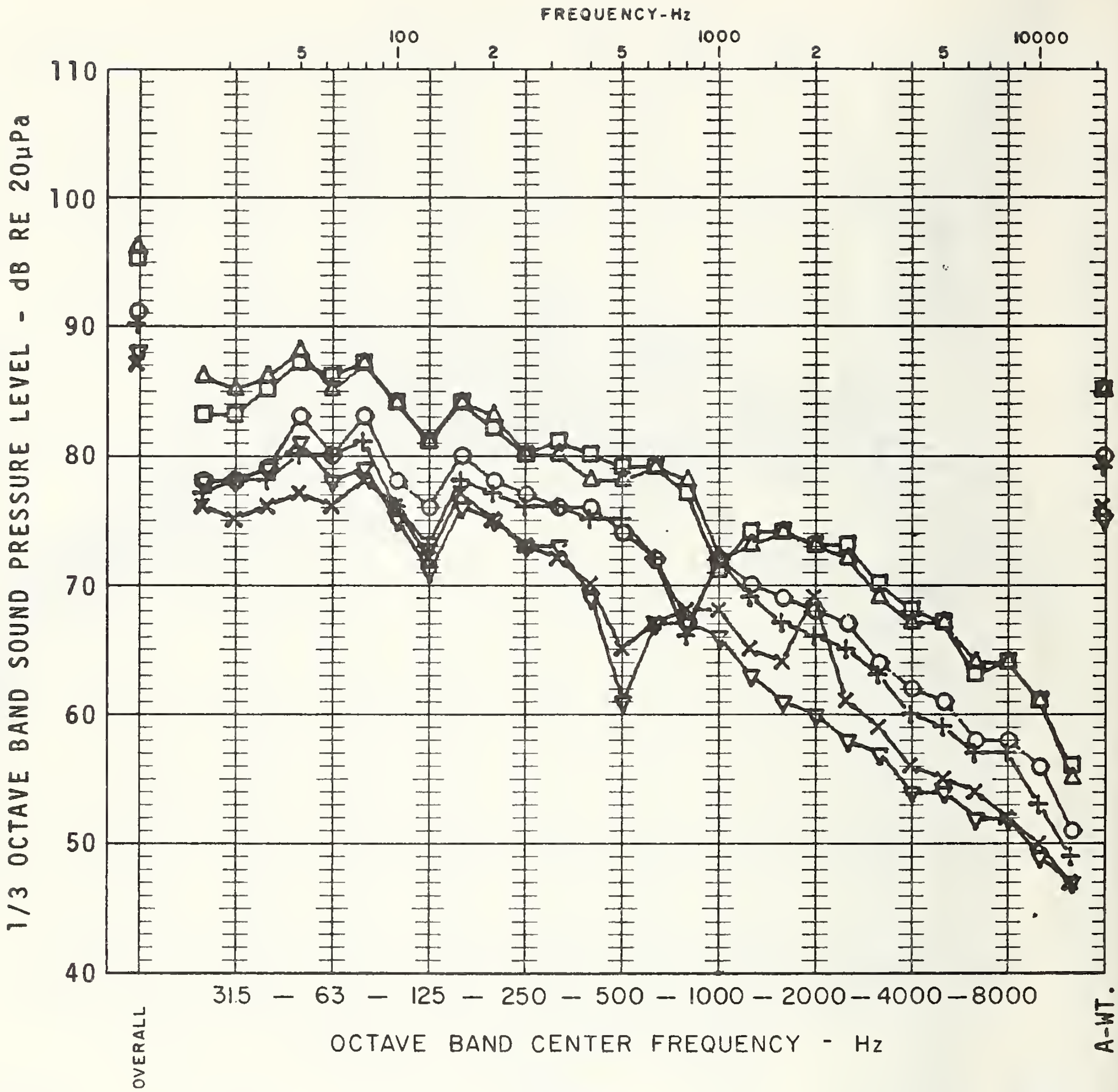


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	NORMAL	63	△—△	NORMAL	65
+—+	REVERSE	72	▽—▽	REVERSE	50
□—□	NORMAL	64	×—×	NORMAL	44
○—○	REVERSE	73	+—+	REVERSE	74
			□—□	NORMAL	62

FIGURE B-12. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IB; AUGUST 17, 1976

WAYSIDE - NEW STANDARD WHEELS

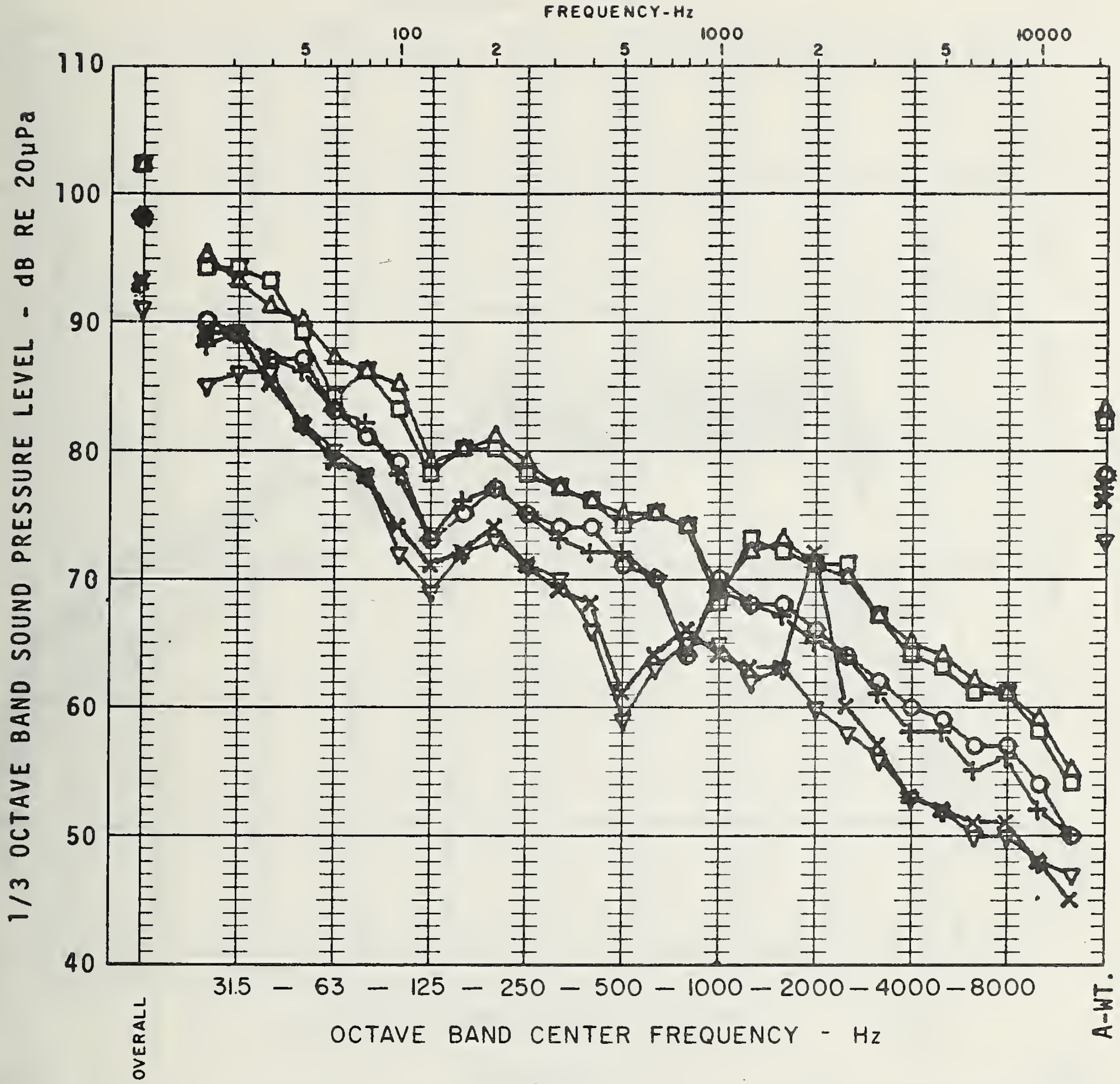


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	41	△—△	REVERSE	81
+—+	NORMAL	58	▽—▽	NORMAL	39
□—□	REVERSE	79			
○—○	NORMAL	59			

FIGURE B-13. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIA; OCTOBER 4, 1976

CAR INTERIOR, OVER TRUCK; TRUED STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
✕—✕	REVERSE	41	△—△	REVERSE	81
+—+	NORMAL	58	▽—▽	NORMAL	39
□—□	REVERSE	79			
○—○	NORMAL	59			

FIGURE B-14. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIA; OCTOBER 4, 1976

CAR INTERIOR AT CENTER - TRUED STANDARD WHEELS

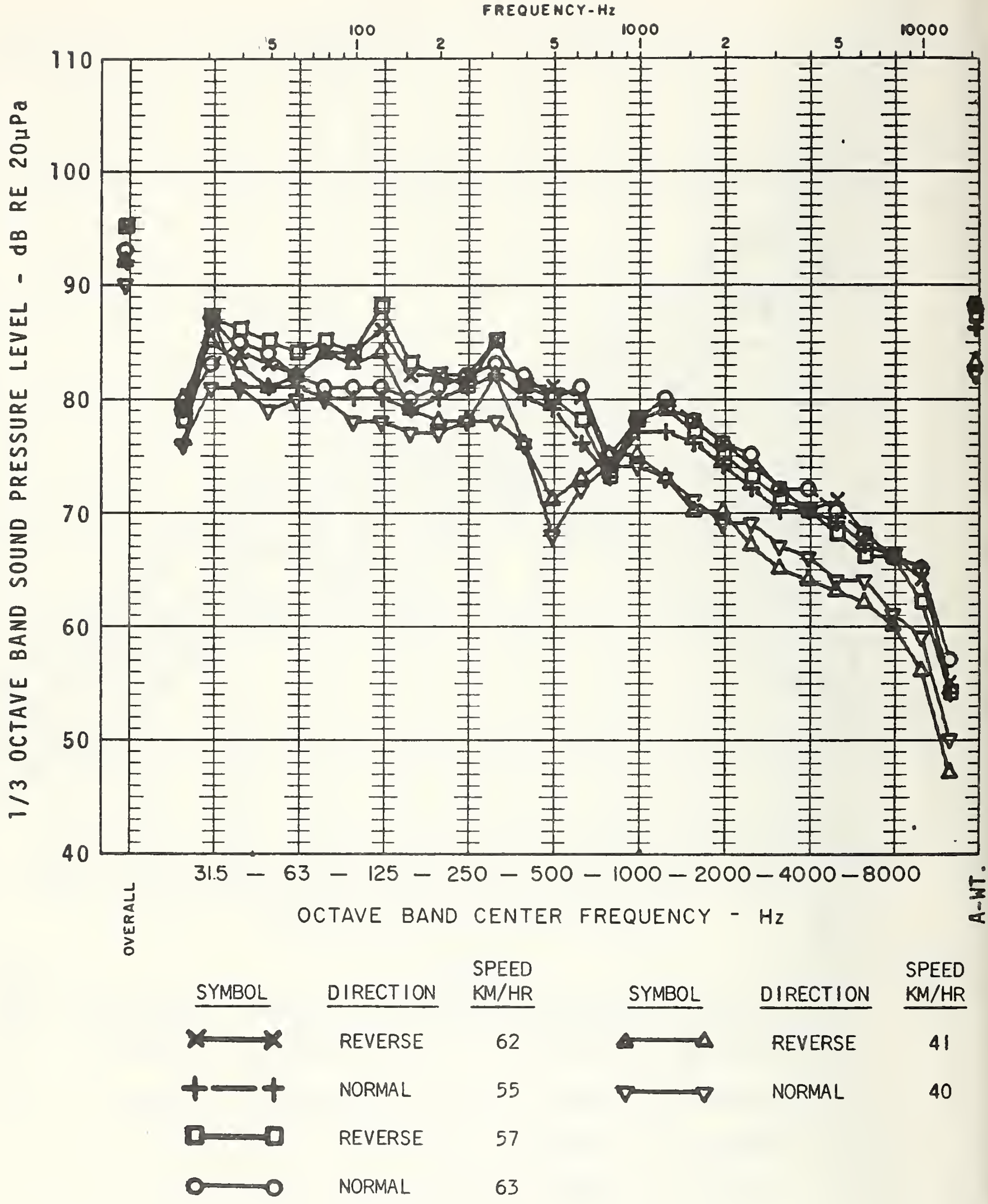
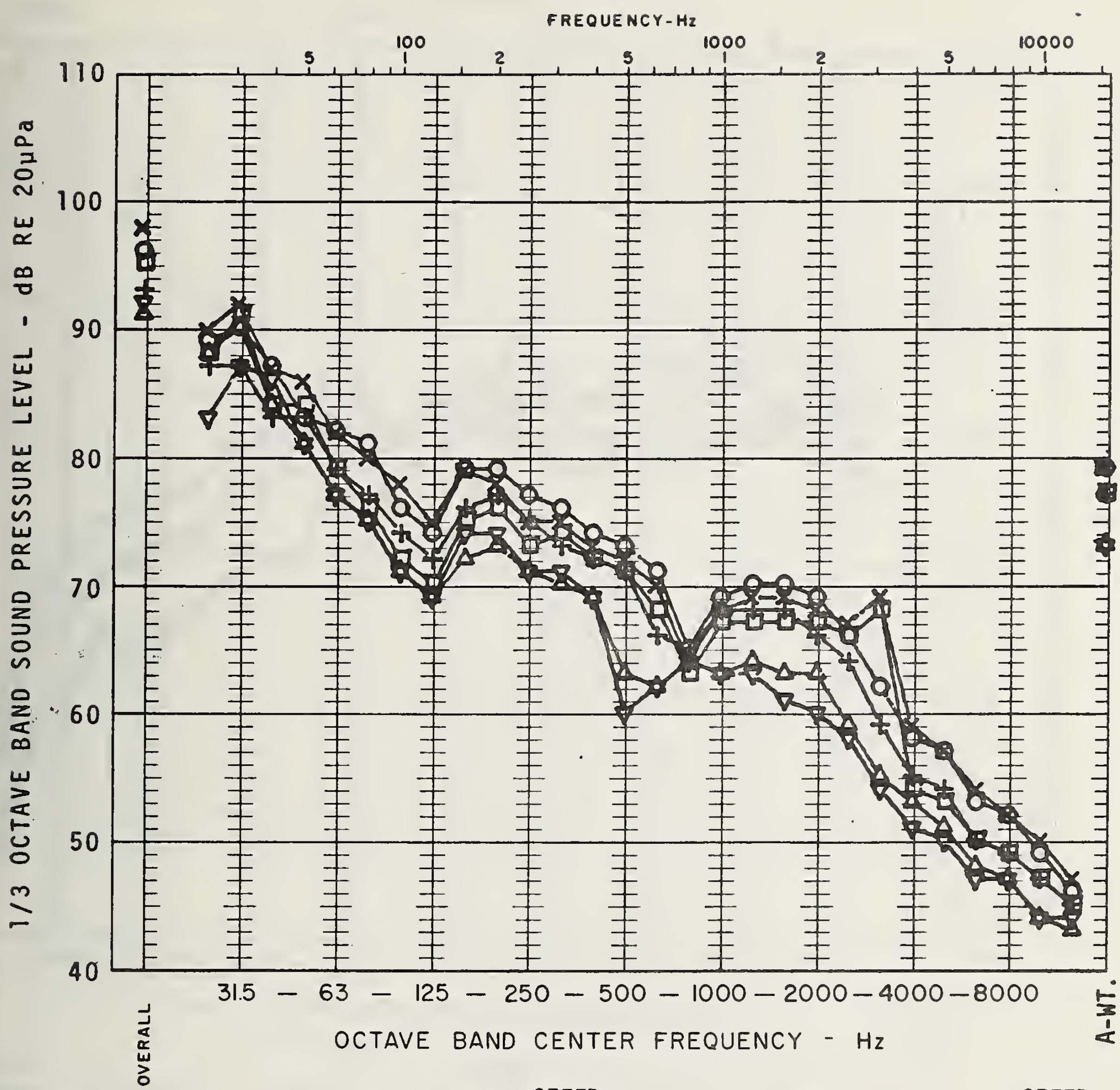
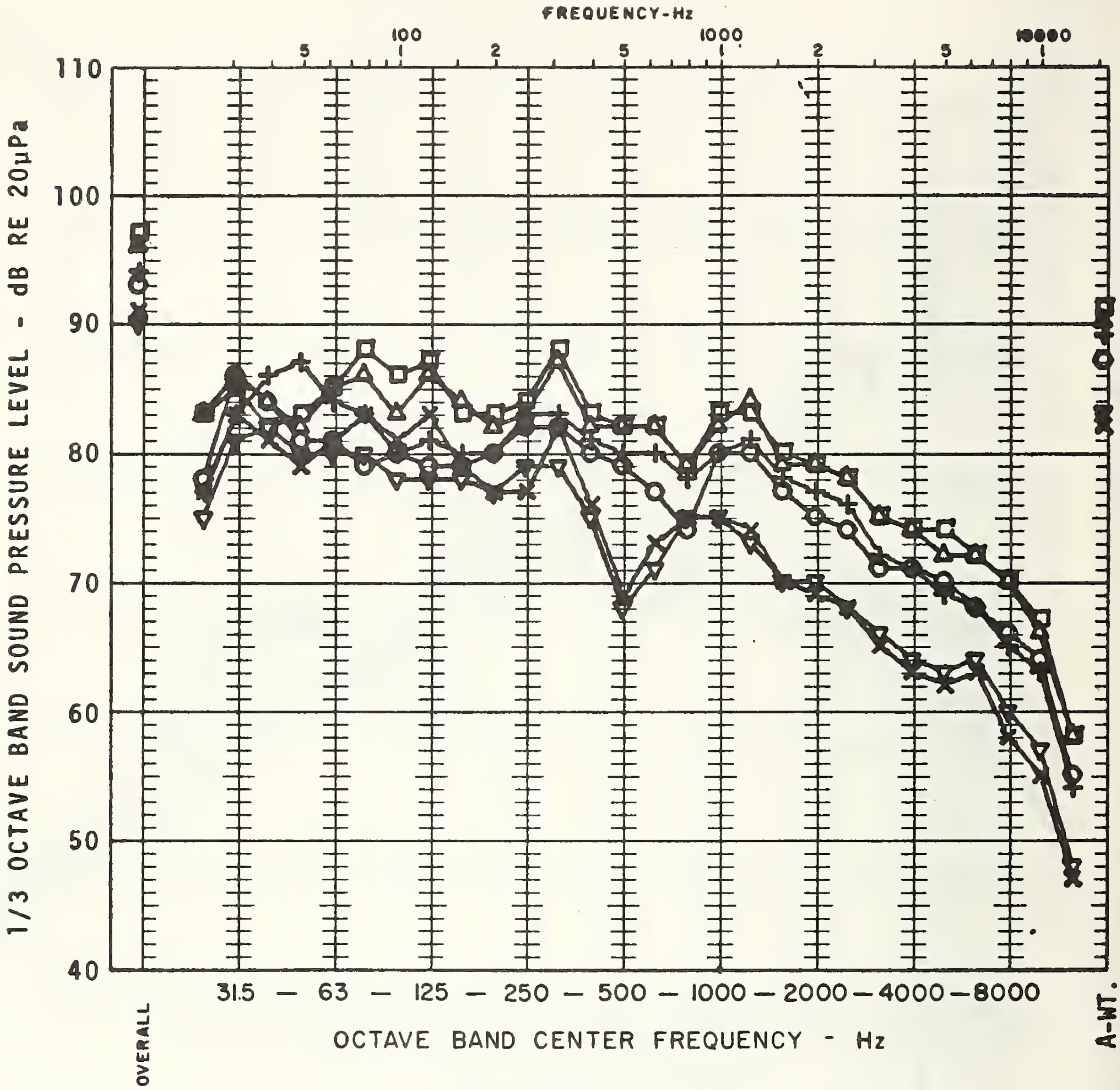


FIGURE B-15. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR, OVER TRUCK - NEW ACOUSTAFLEX RESILIENT WHEEL



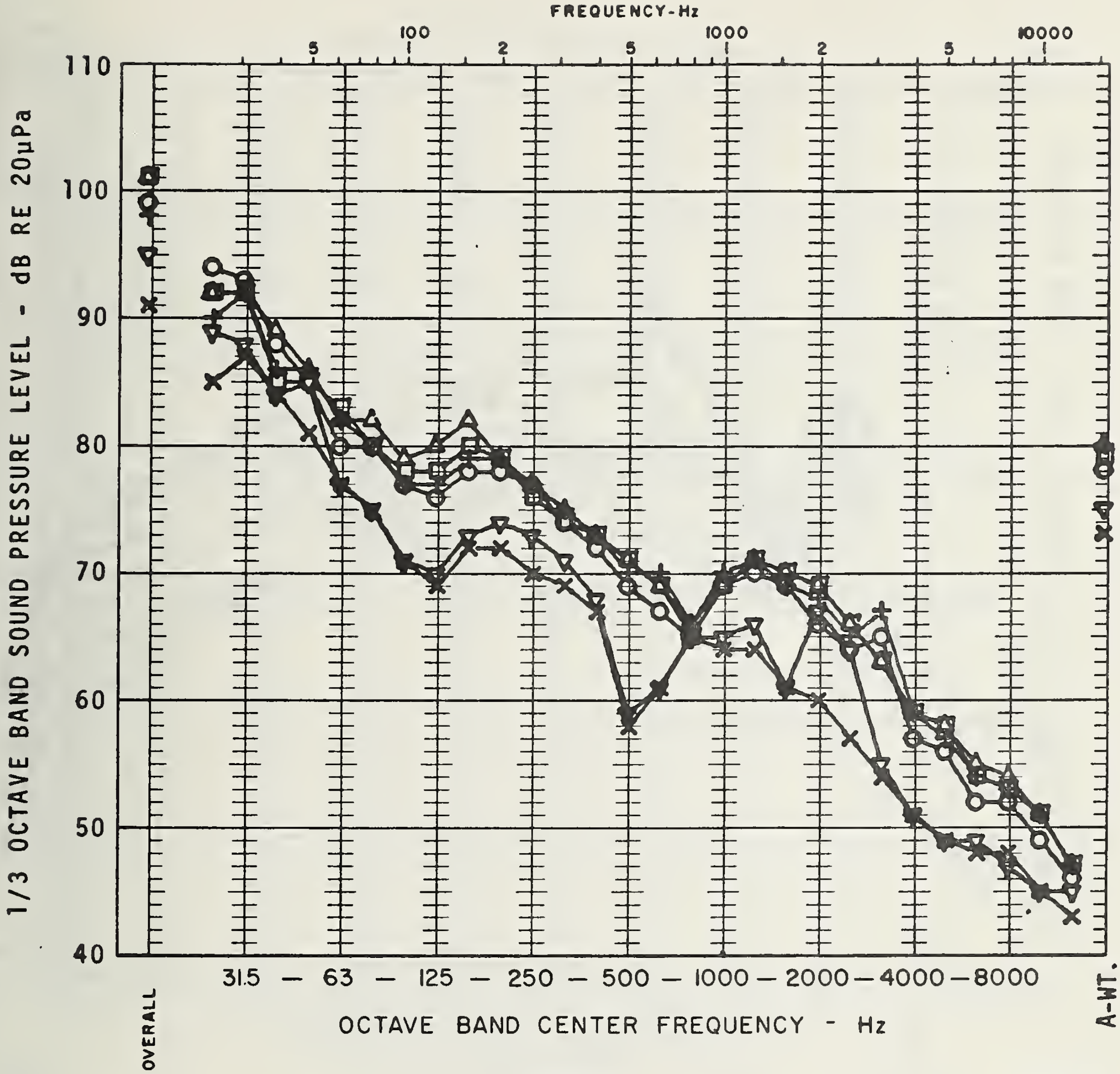
SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	62	△——△	REVERSE	41
+——+	NORMAL	55	▽——▽	NORMAL	40
□——□	REVERSE	57			
○——○	NORMAL	63			

FIGURE B-16. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR AT CENTER - NEW ACOUSTAFLEX RESILIENT WHEELS



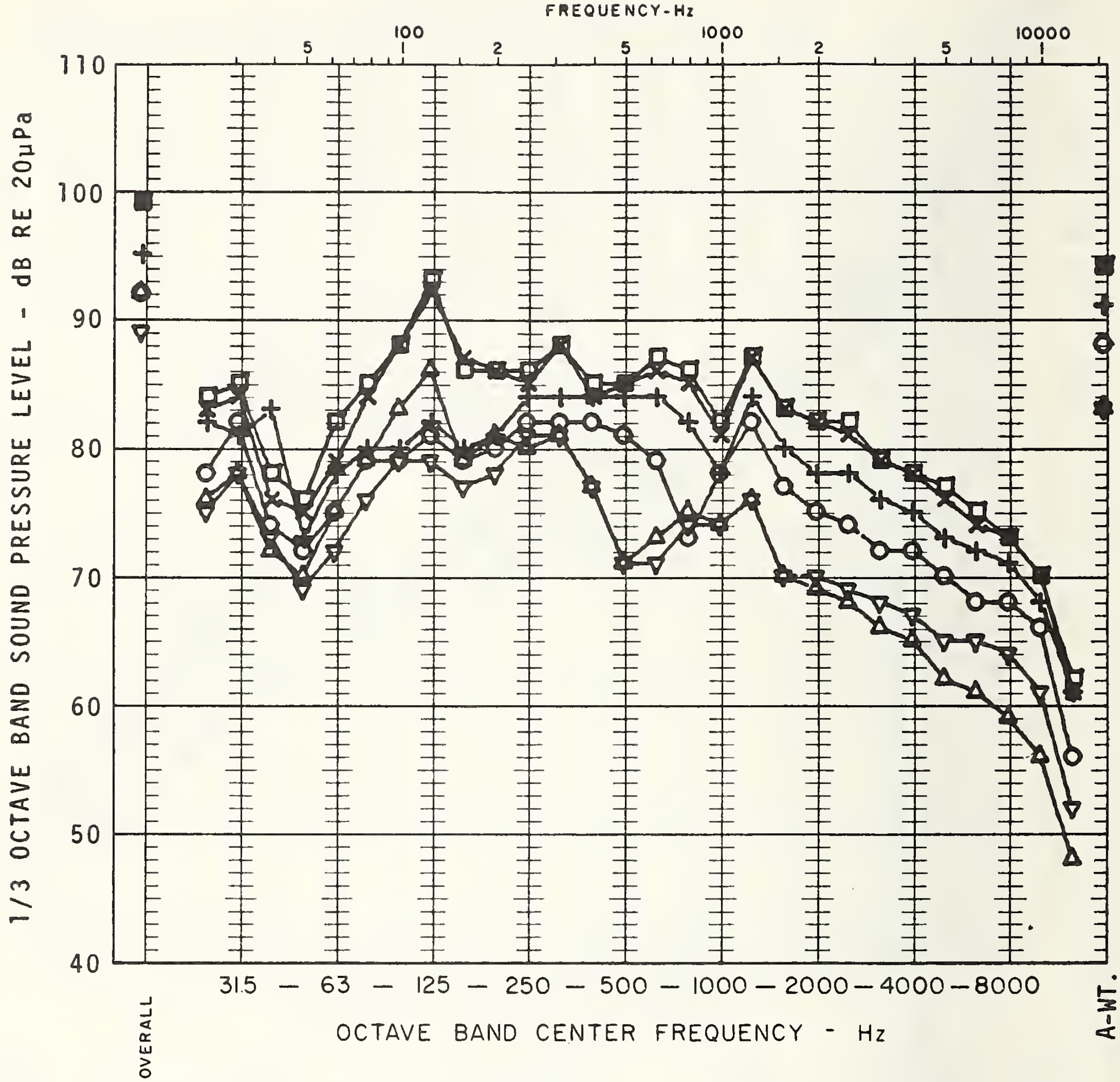
SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	40	△—△	REVERSE	67
+—+	NORMAL	65	▽—▽	NORMAL	41
□—□	REVERSE	65			
○—○	NORMAL	59			

FIGURE B-17. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR, OVER TRUCK - NEW PENN BOCHUM RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
X—X	REVERSE	40	△—△	REVERSE	67
+—+	NORMAL	65	▽—▽	NORMAL	41
□—□	REVERSE	65			
○—○	NORMAL	59			

FIGURE B-18. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR AT CENTER - NEW PENN BOCHUM RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	77	△—△	REVERSE	41
+—+	NORMAL	71	▽—▽	NORMAL	42
□—□	REVERSE	78			
○—○	NORMAL	59			

FIGURE B-19. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR, OVER TRUCK - NEW SAB RESILIENT WHEELS

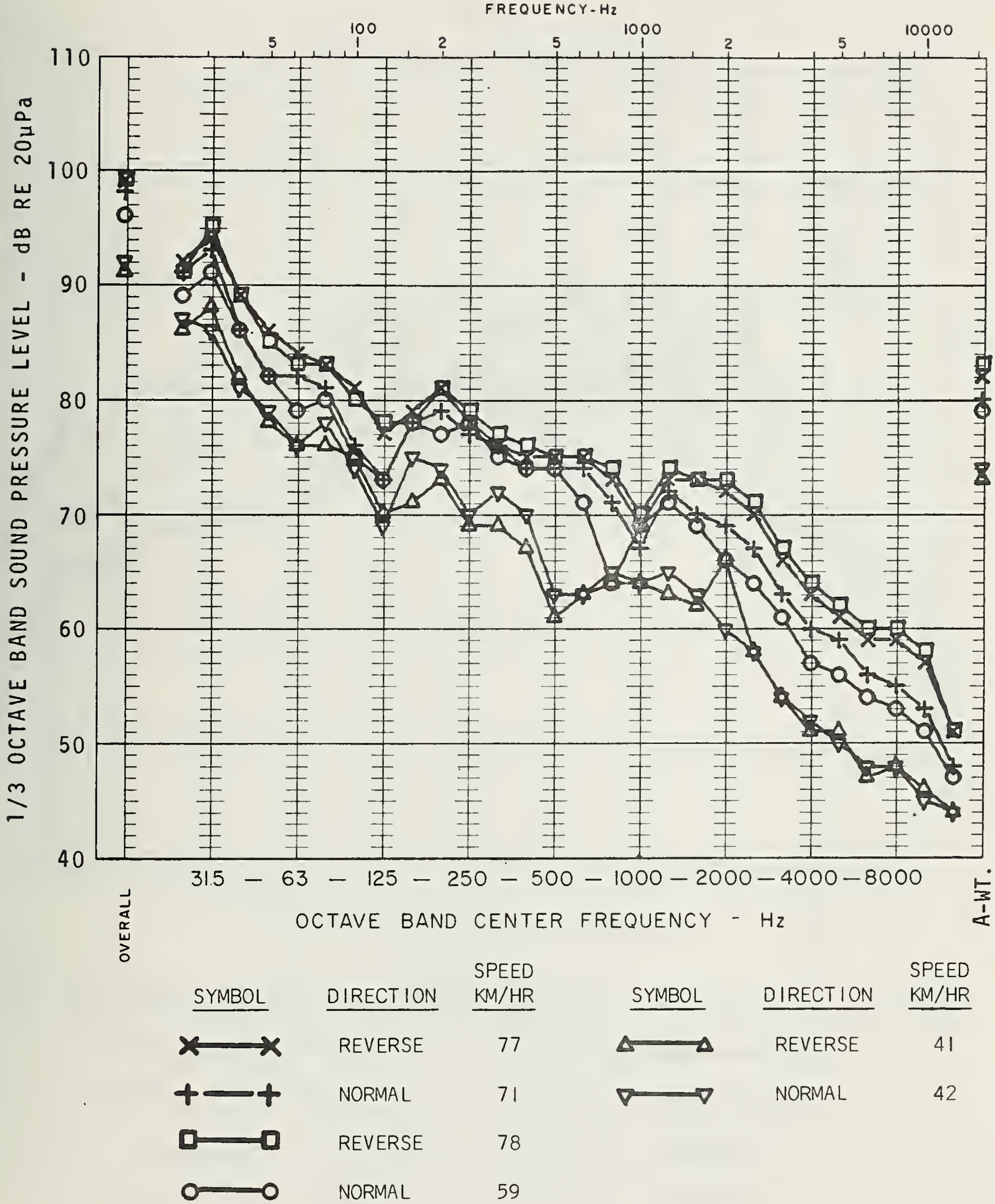
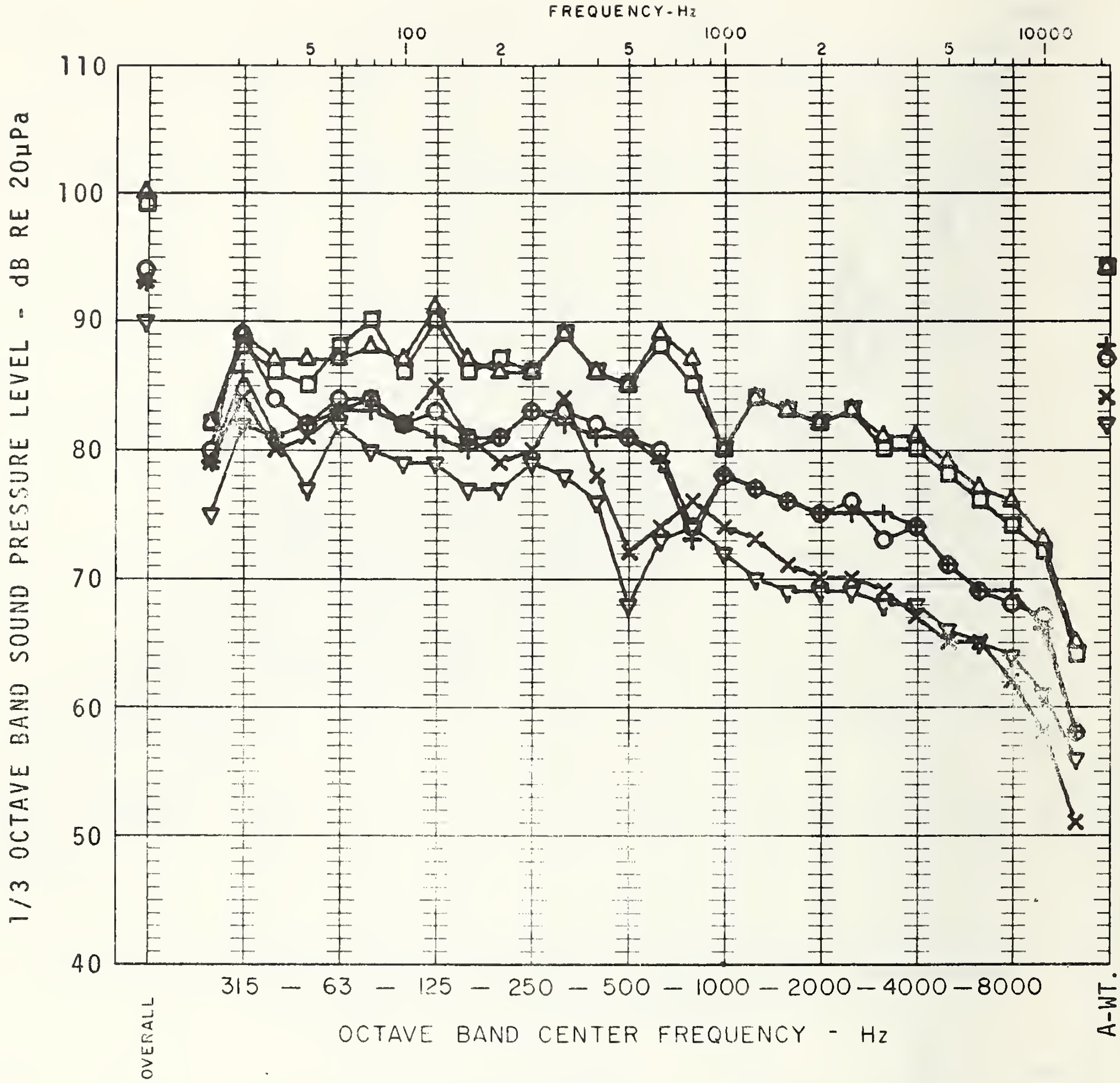


FIGURE B-20. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIA; OCTOBER 4, 1976
CAR INTERIOR AT CENTER - NEW SAB RESILIENT WHEELS

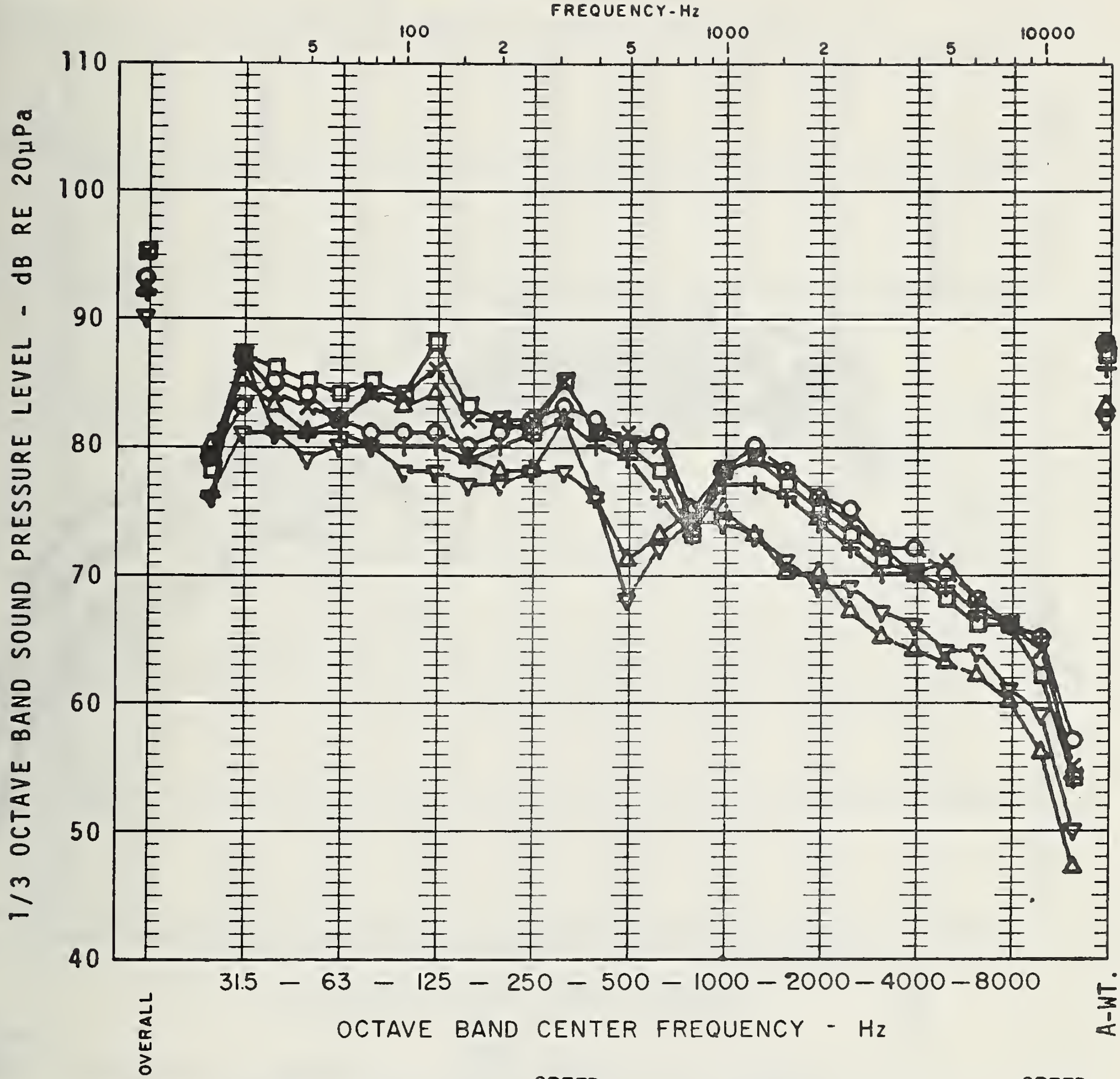


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	41	△—△	REVERSE	81
+—+	NORMAL	58	▽—▽	NORMAL	39
□—□	REVERSE	79			
○—○	NORMAL	59			

FIGURE B-21. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIA; OCTOBER 4, 1976

WAYSIDE - TRUED STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	62	△—△	REVERSE	41
+—+	NORMAL	55	▽—▽	NORMAL	40
□—□	REVERSE	57			
○—○	NORMAL	63			

FIGURE B-22. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIA; OCTOBER 4, 1976

WAYSIDE - NEW ACOUSTAFLEX RESILIENT WHEELS

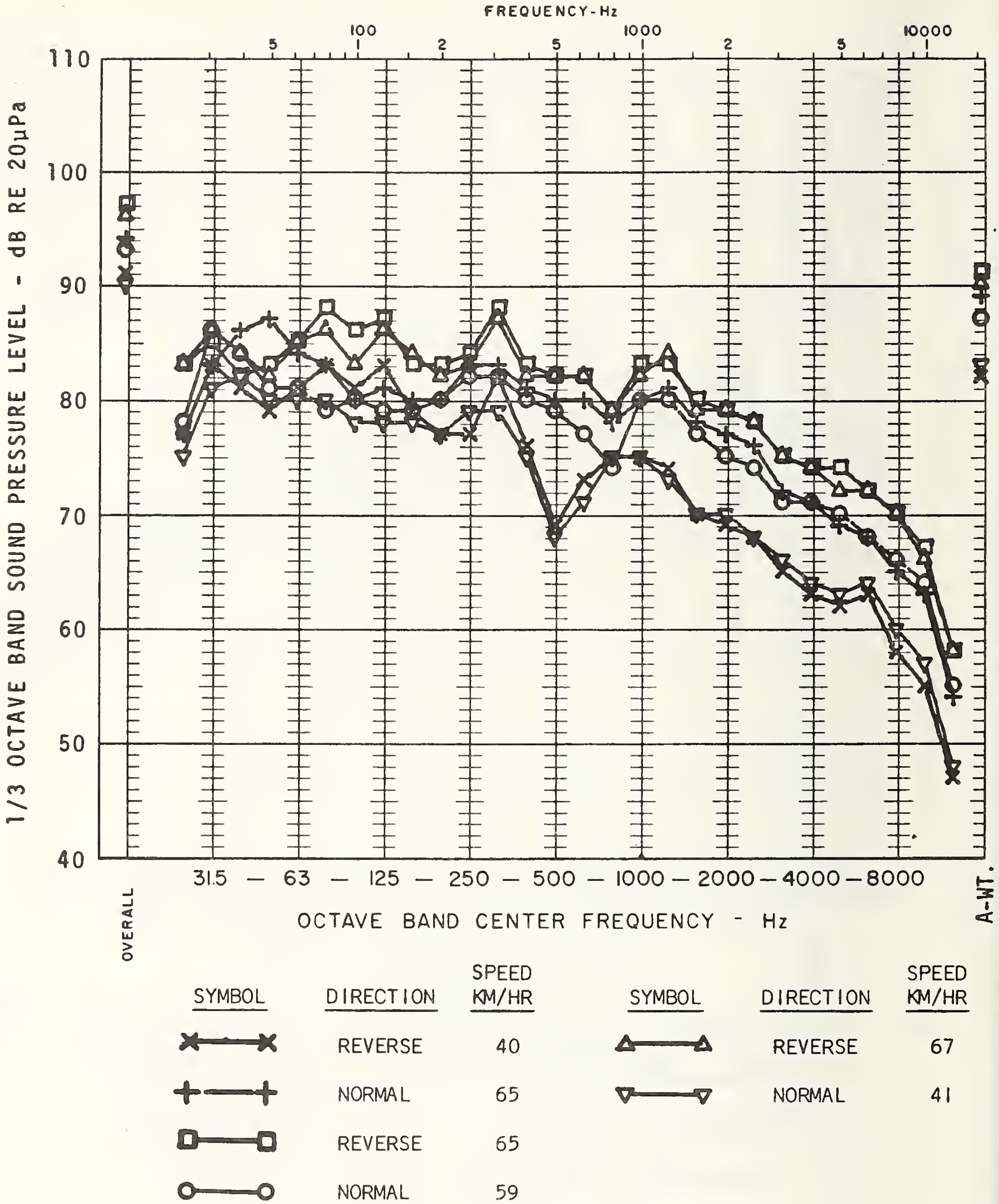
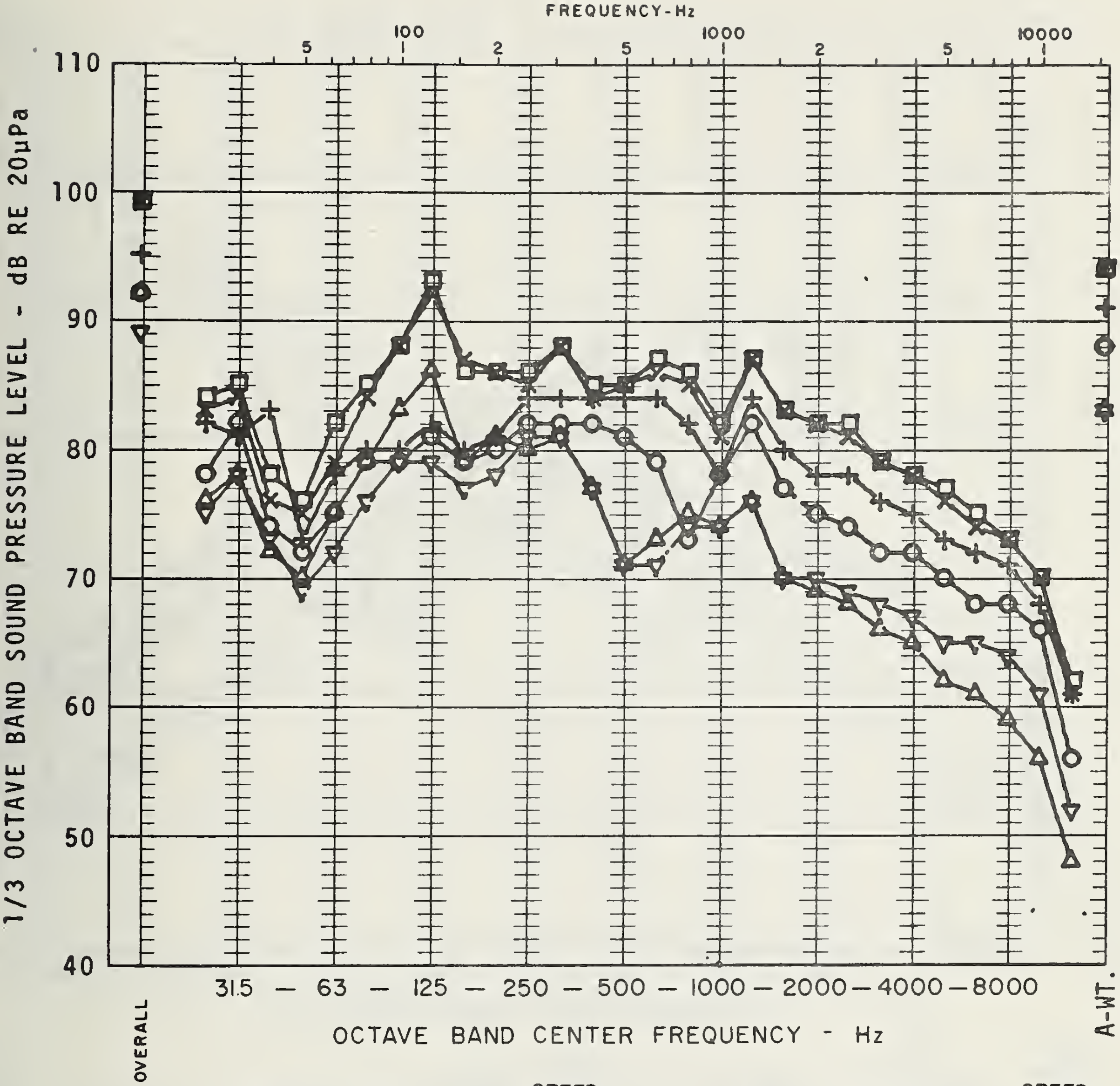


FIGURE B-23. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIA; OCTOBER 4, 1976

WAYSIDE - NEW PENN BOCHUM RESILIENT WHEELS

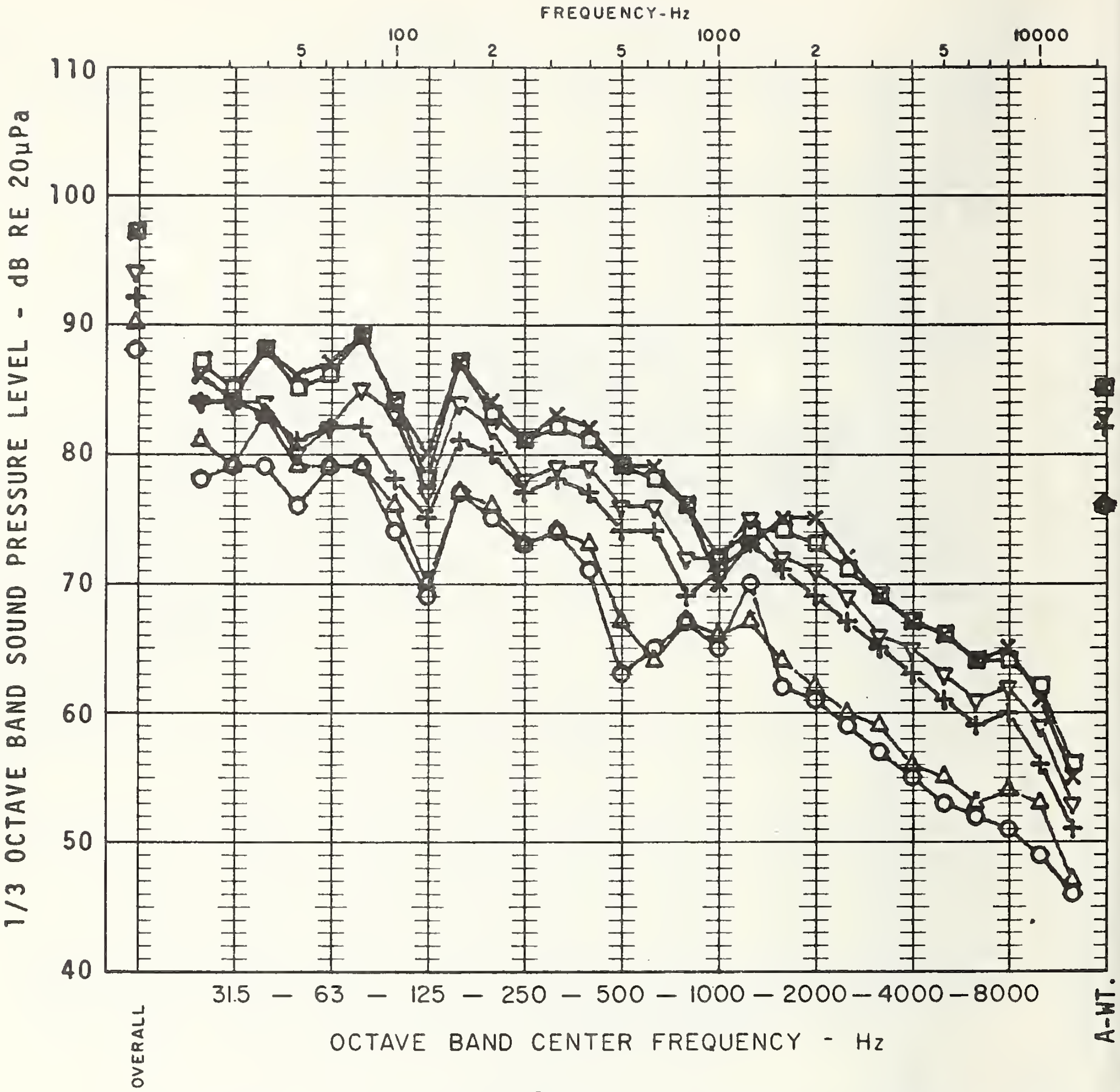


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	77	△—△	REVERSE	41
+—+	NORMAL	71	▽—▽	NORMAL	42
□—□	REVERSE	78			
○—○	NORMAL	59			

FIGURE B-24. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIA; OCTOBER 4, 1976

WAYSIDE - NEW SAB RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	78	△——△	REVERSE	44
+——+	NORMAL	60	▽——▽	NORMAL	67
□——□	REVERSE	76			
○——○	NORMAL	40			

FIGURE B-25. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIB; OCTOBER 14, 1976

CAR INTERIOR, OVER TRUCK - WORN STANDARD WHEELS

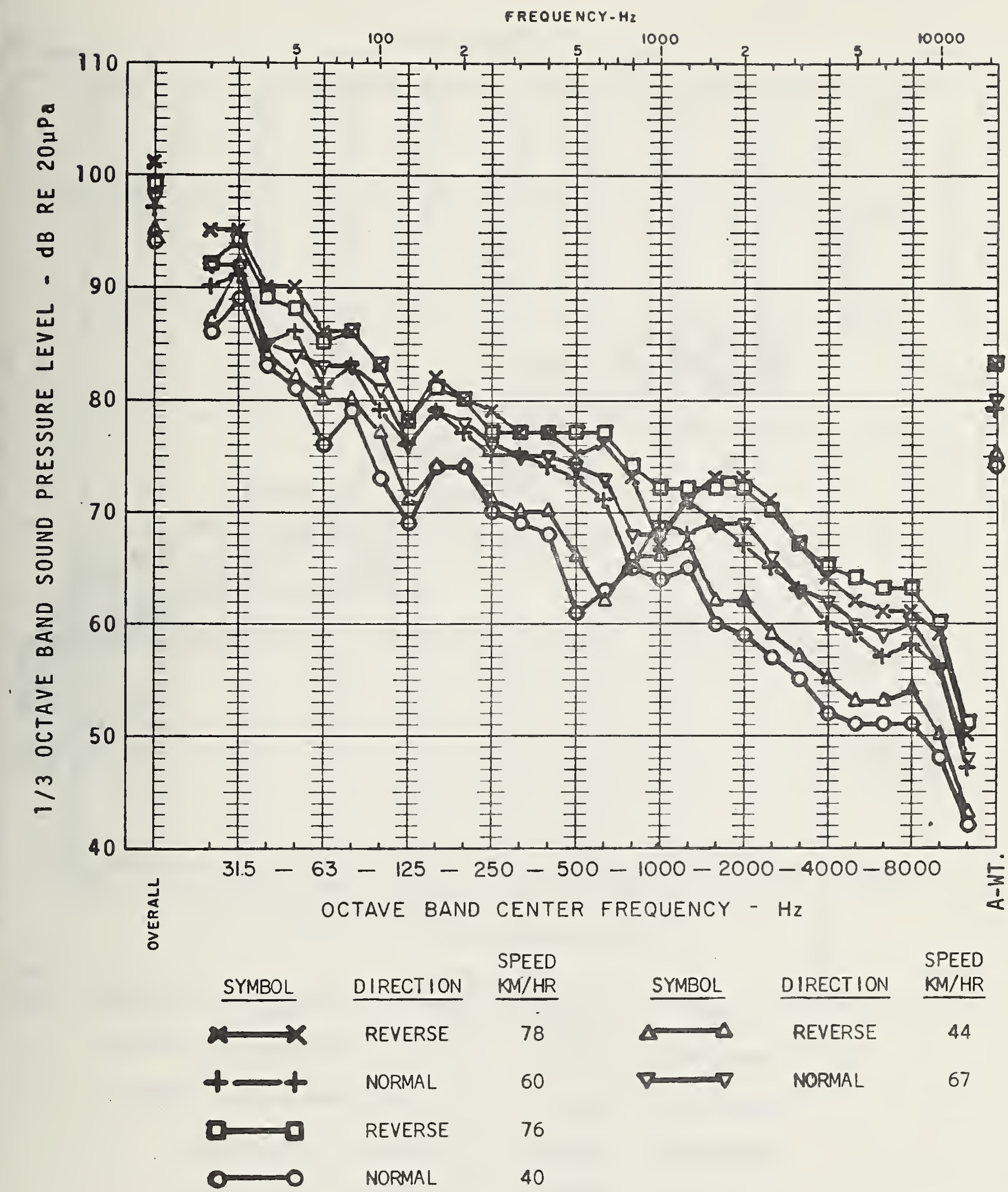
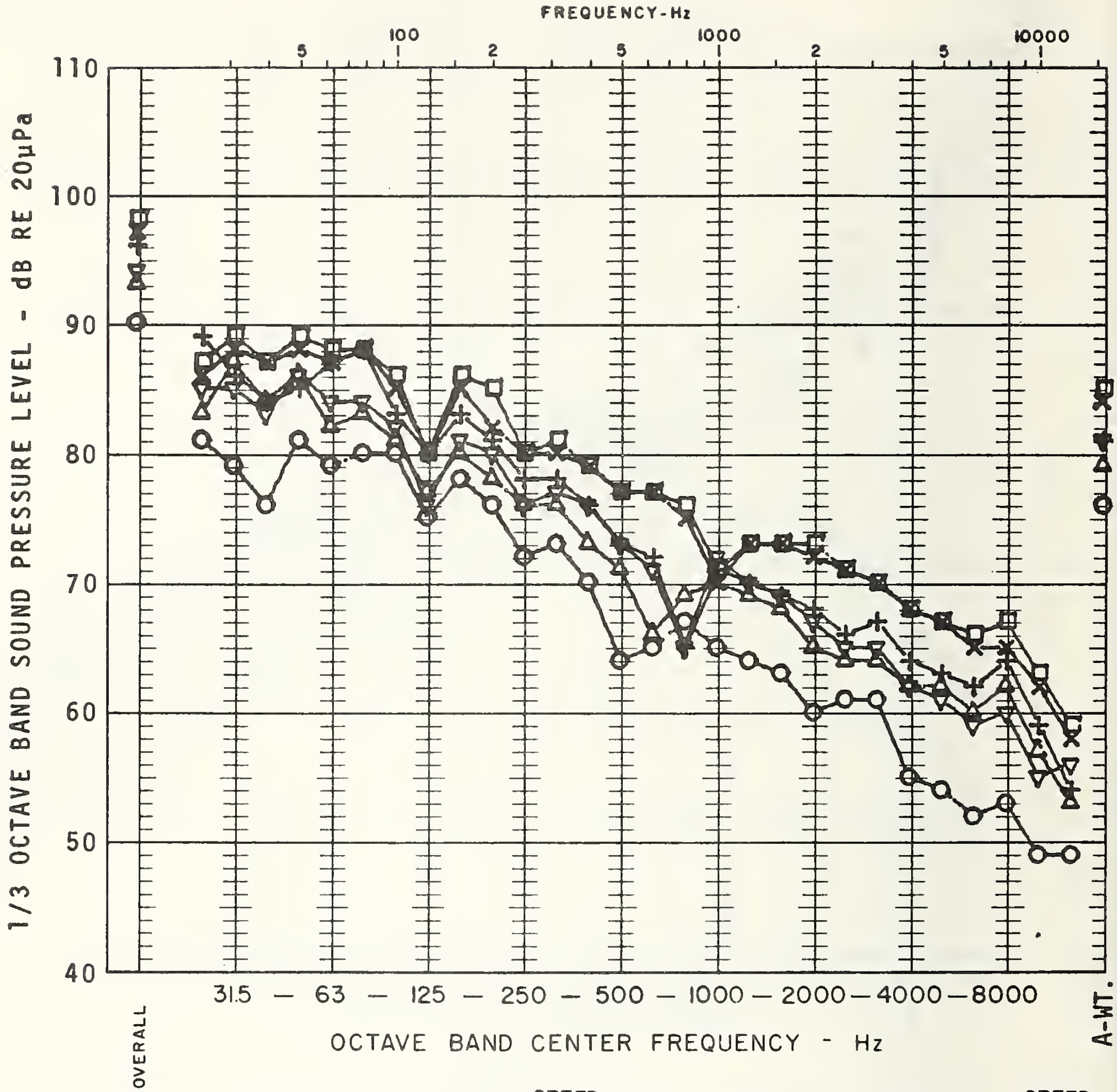


FIGURE B-26. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIB; OCTOBER 14, 1976

CAR INTERIOR AT CENTER - WORN STANDARD WHEELS

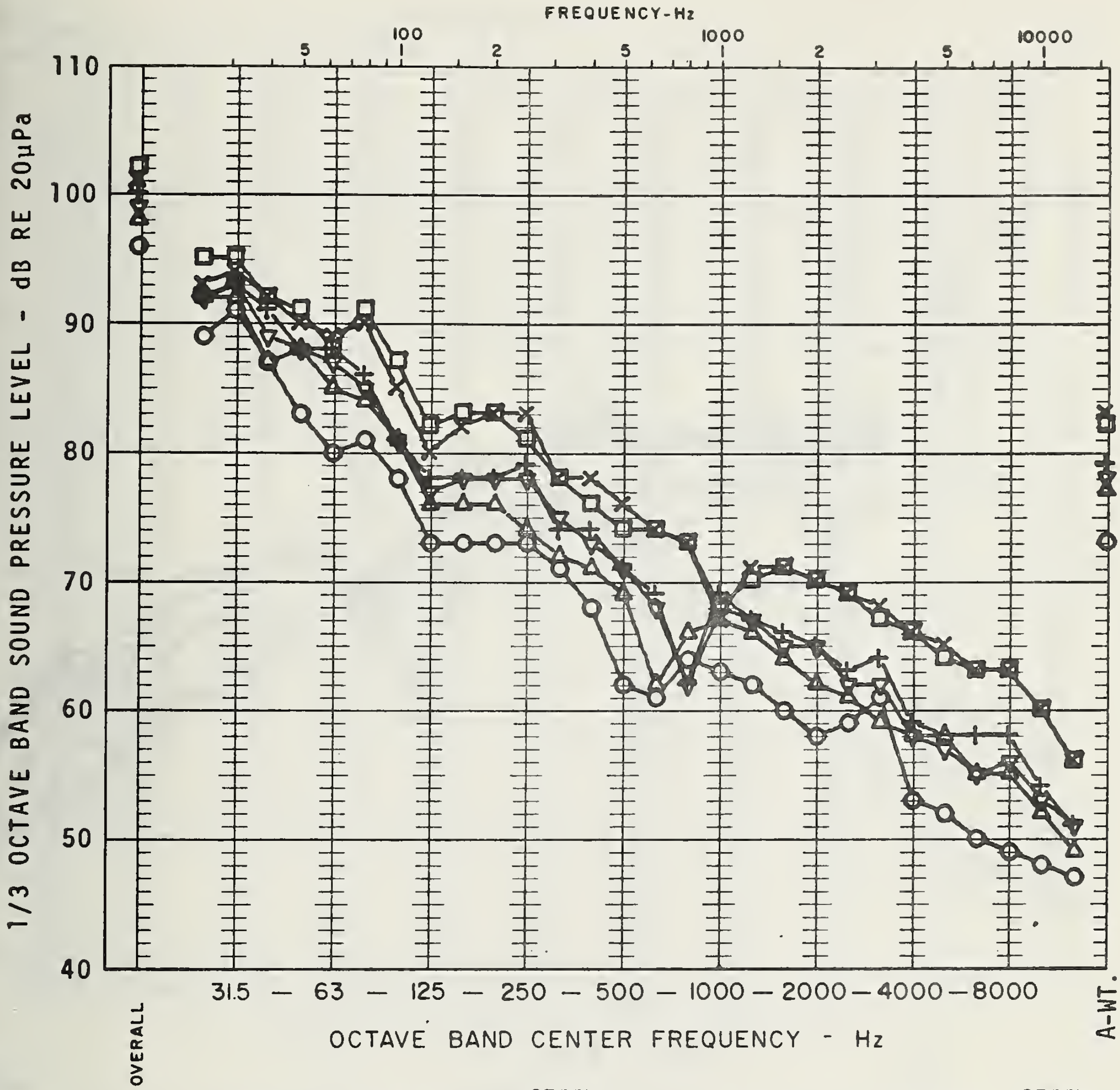


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	80	△—△	REVERSE	51
+—+	NORMAL	60	▽—▽	NORMAL	60
□—□	REVERSE	82			
○—○	NORMAL	42			

FIGURE B-27. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIB; OCTOBER 14, 1976

CAR INTERIOR, OVER TRUCK - TRUED STANDARD WHEELS

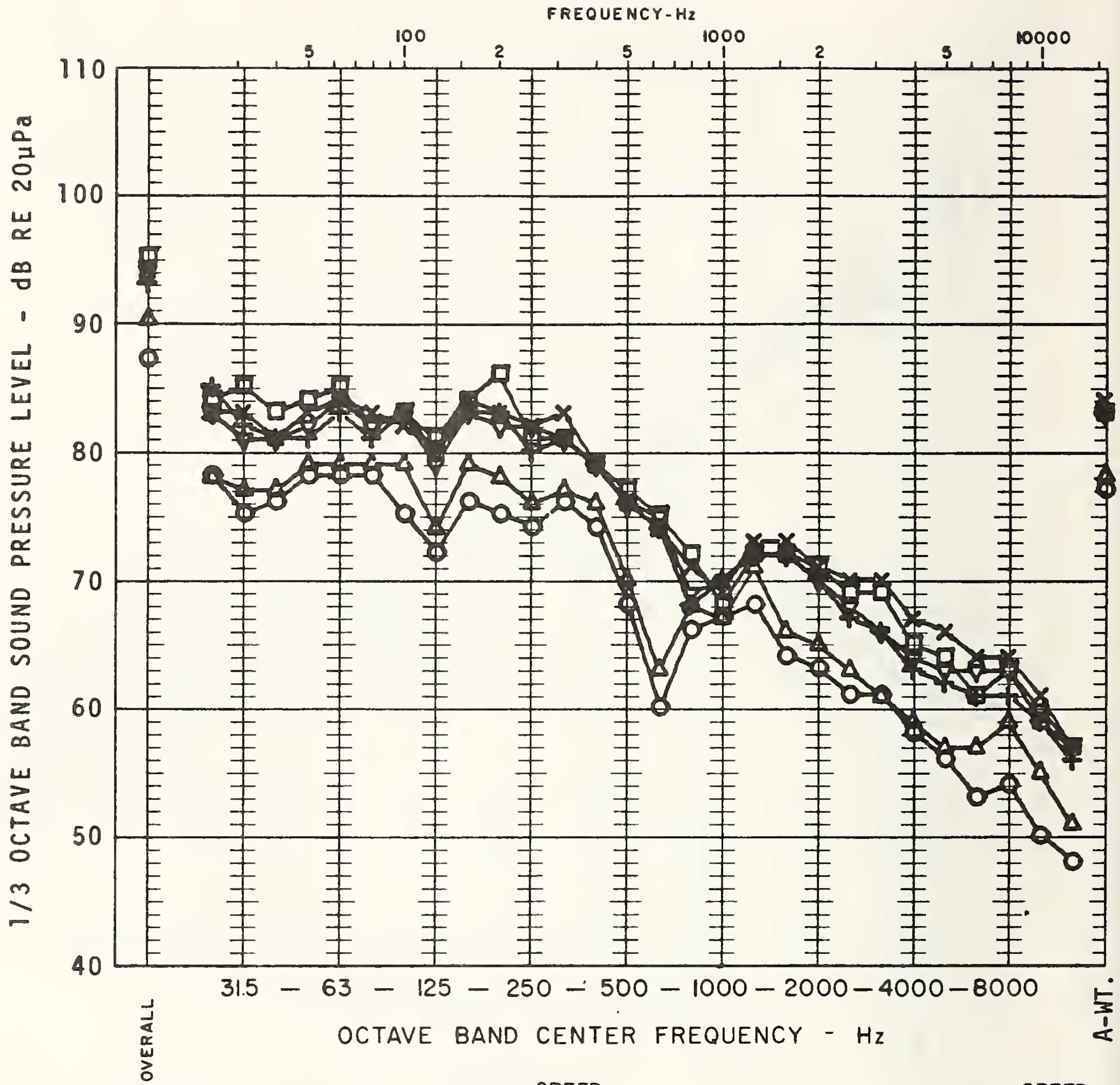


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	80	△—△	REVERSE	51
+—+	NORMAL	60	▽—▽	NORMAL	60
□—□	REVERSE	82			
○—○	NORMAL	42			

FIGURE B-28. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

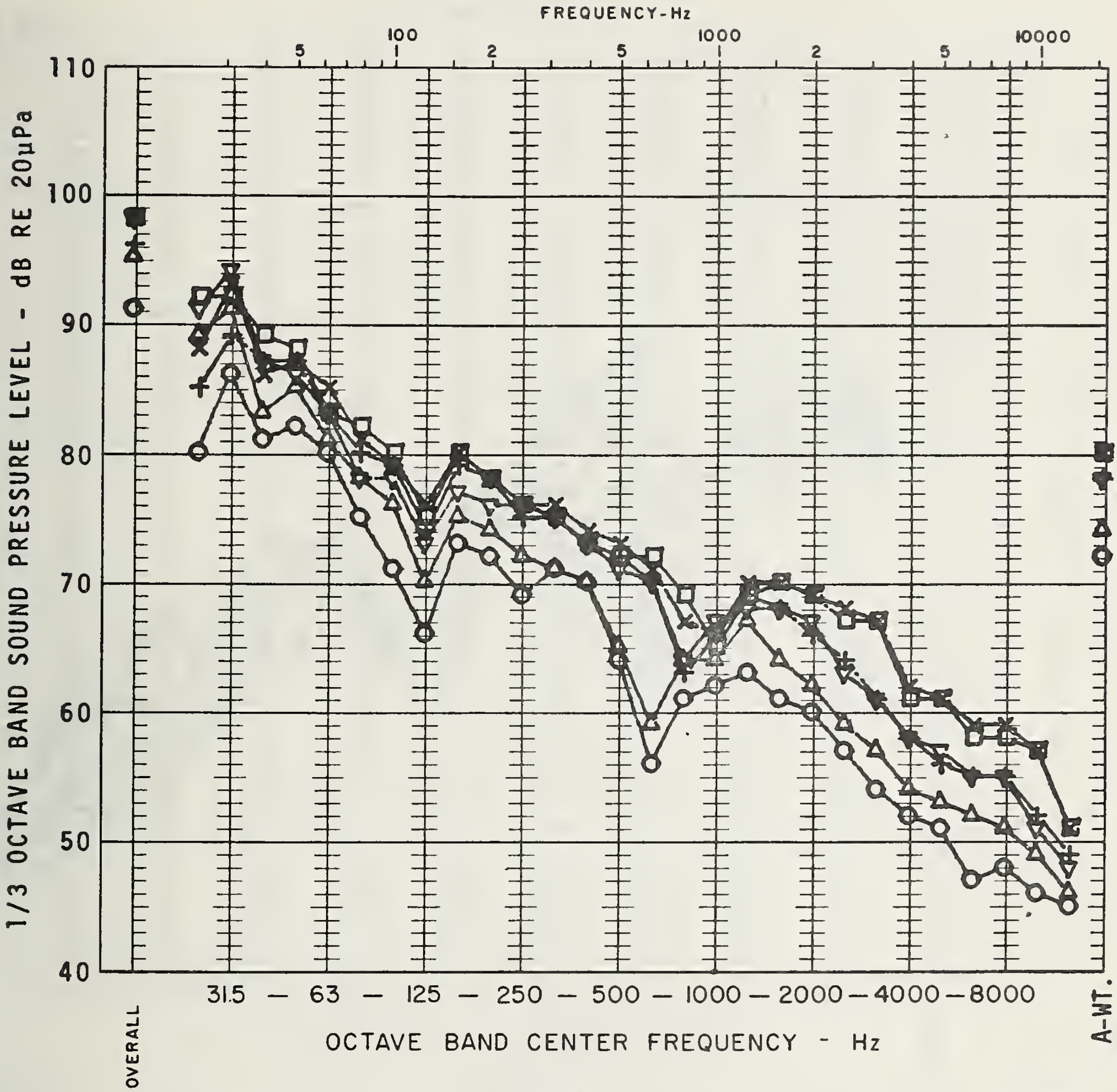
PHASE IIB; OCTOBER 14, 1976

CAR INTERIOR AT CENTER - TRUED STANDARD WHEELS



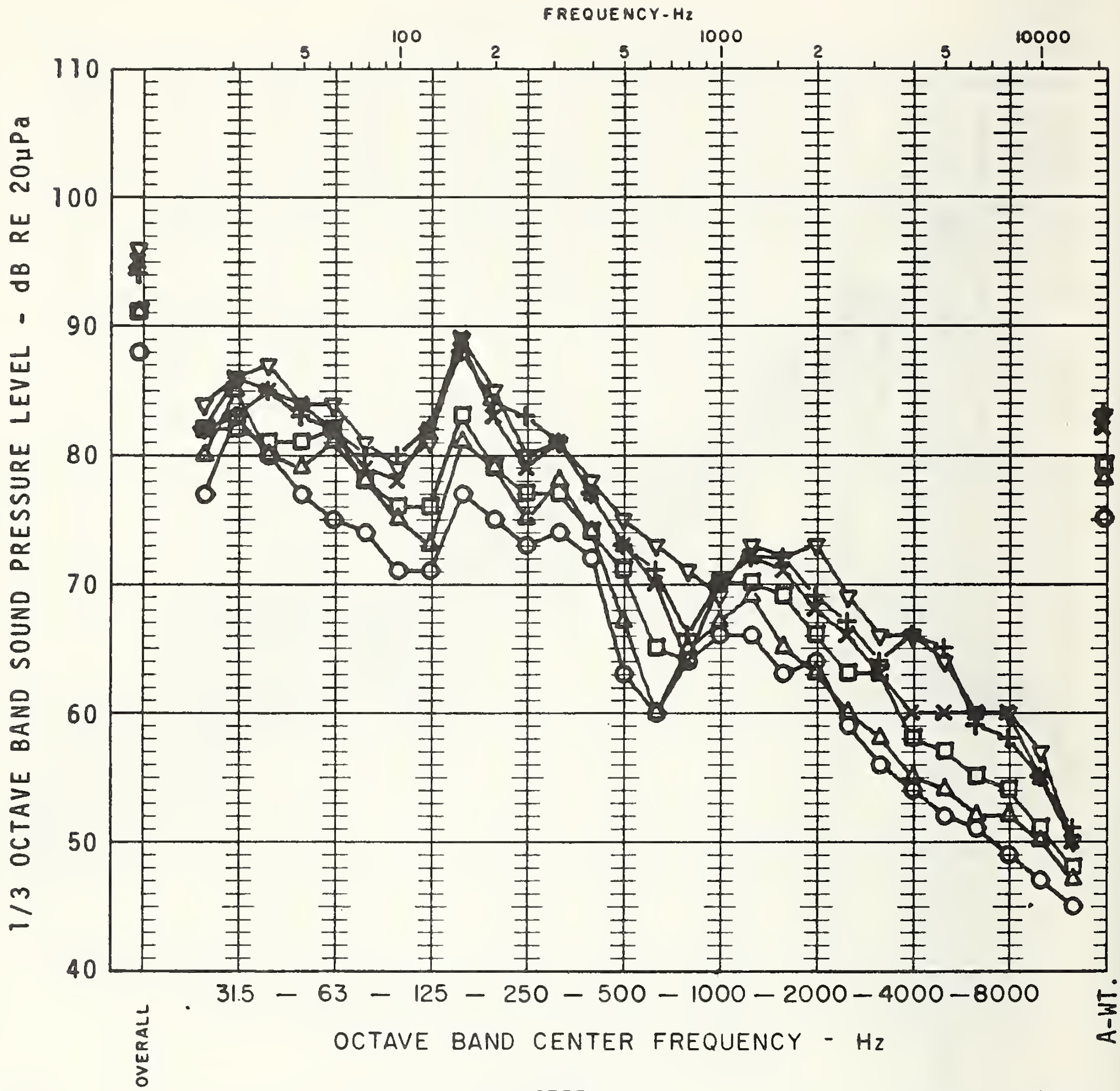
SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
X—X	REVERSE	69	Δ—Δ	REVERSE	46
+—+	NORMAL	64	▽—▽	NORMAL	64
□—□	REVERSE	74			
○—○	NORMAL	46			

FIGURE B-29. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR, OVER TRUCK - NEW ACOUSTAFLEX RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	69	△——△	REVERSE	46
+——+	NORMAL	64	▽——▽	NORMAL	64
□——□	REVERSE	74			
○——○	NORMAL	46			

FIGURE B-30. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR AT CENTER - NEW ACOUSTAFLEX RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	61	△——△	REVERSE	46
+——+	NORMAL	64	▽——▽	NORMAL	74
□——□	REVERSE	54			
○——○	NORMAL	42			

FIGURE B-31. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR, OVER TRUCK - NEW PENN BOCHUM RESILIENT WHEELS

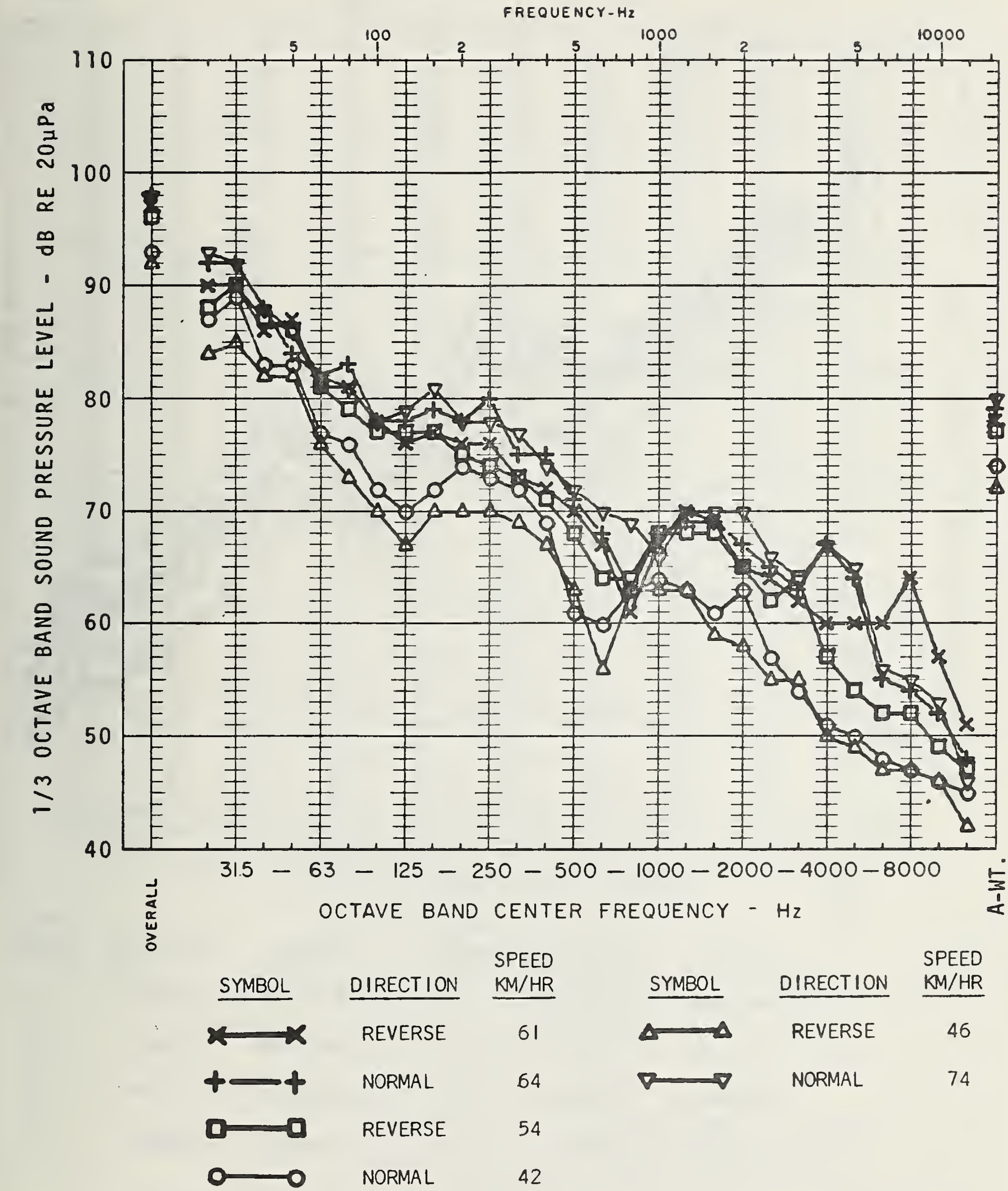
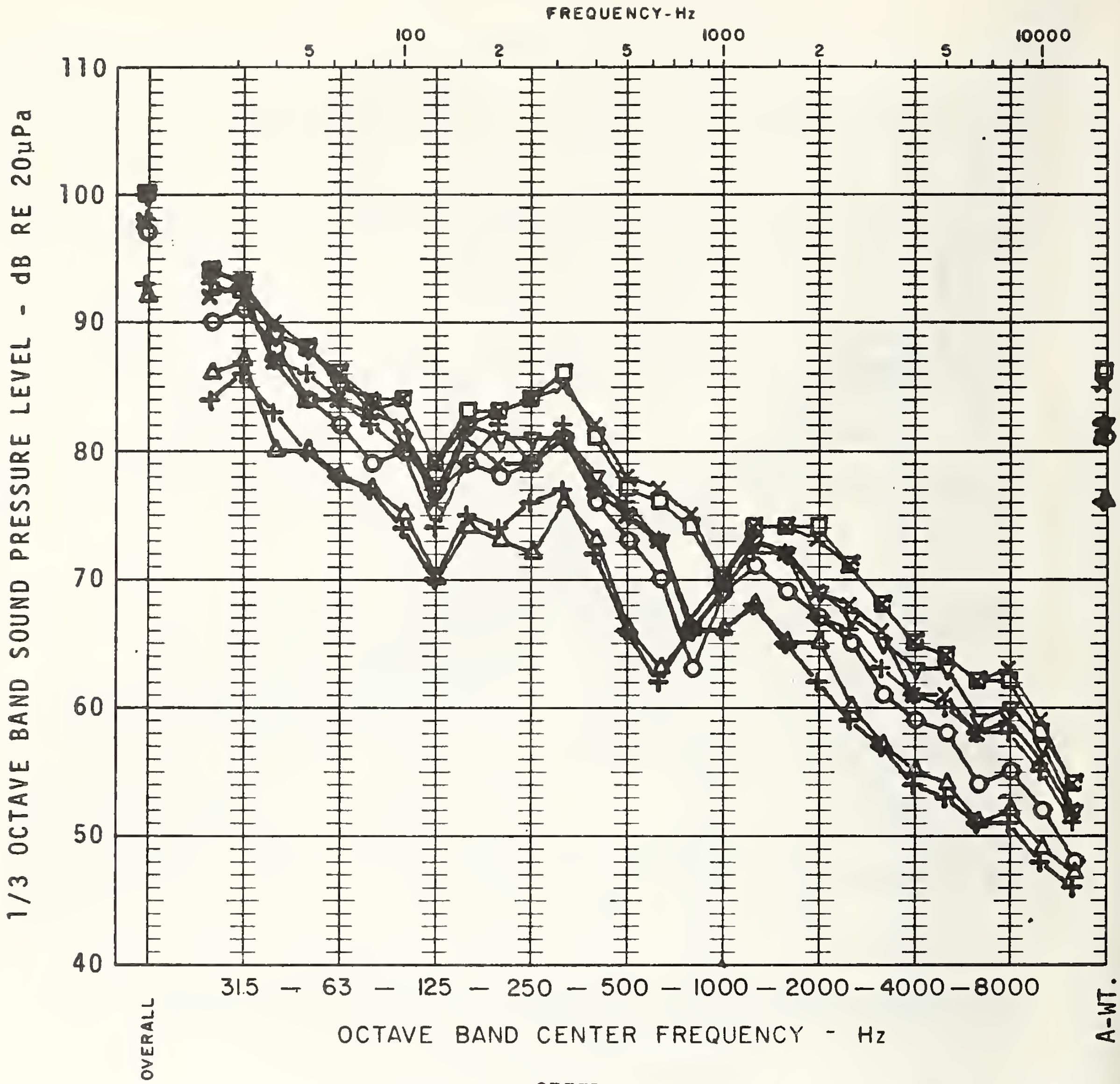


FIGURE B-32. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR AT CENTER - NEW PENN BOCHUM RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
✕—✕	REVERSE	80	△—△	REVERSE	43
+—+	NORMAL	62	▽—▽	NORMAL	63
□—□	REVERSE	81	×—×	REVERSE	65
○—○	NORMAL	60	+—+	NORMAL	43

FIGURE B-33. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIB; OCTOBER 14, 1976

CAR INTERIOR, OVER TRUCK - NEW SAB RESILIENT WHEEL

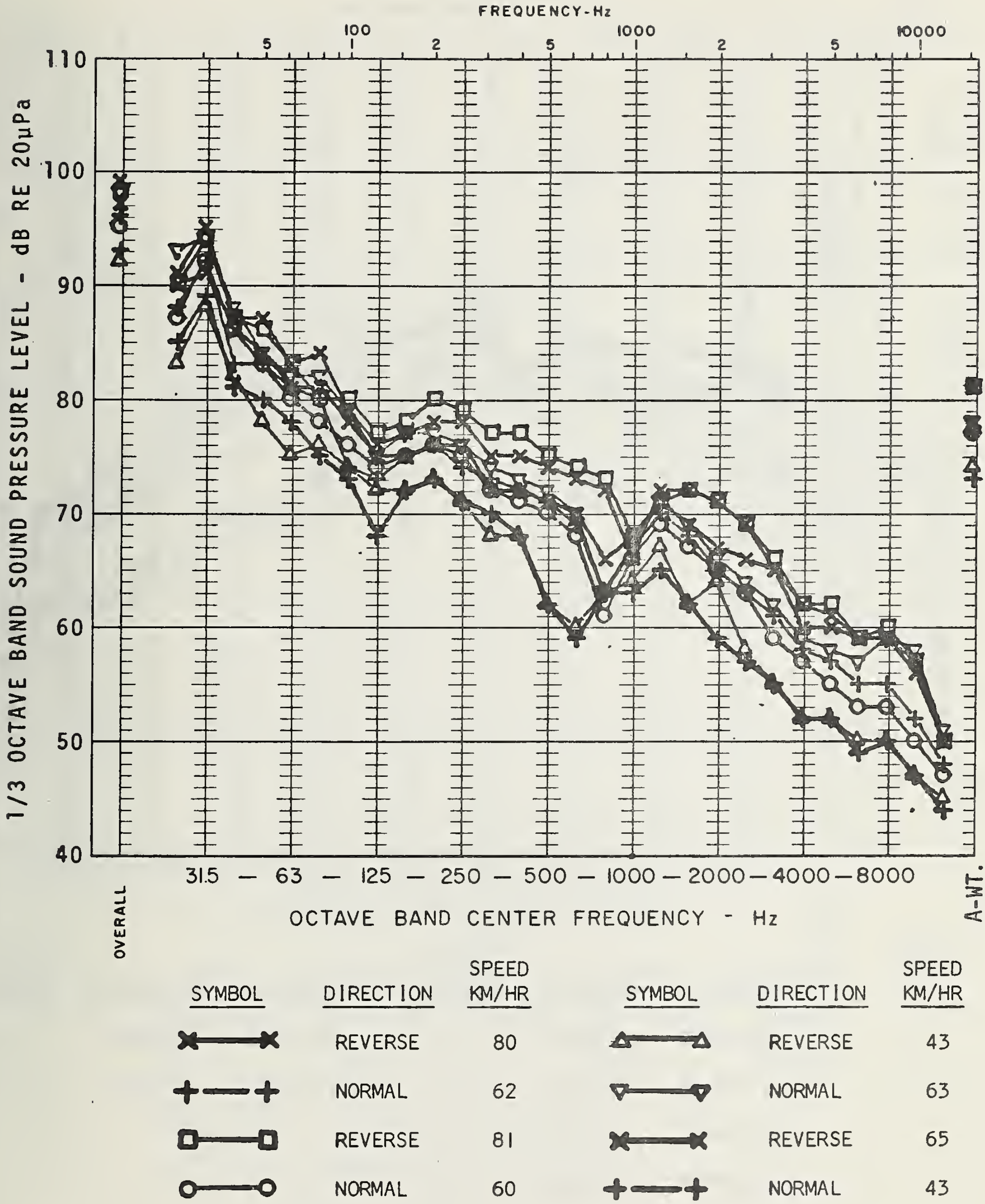
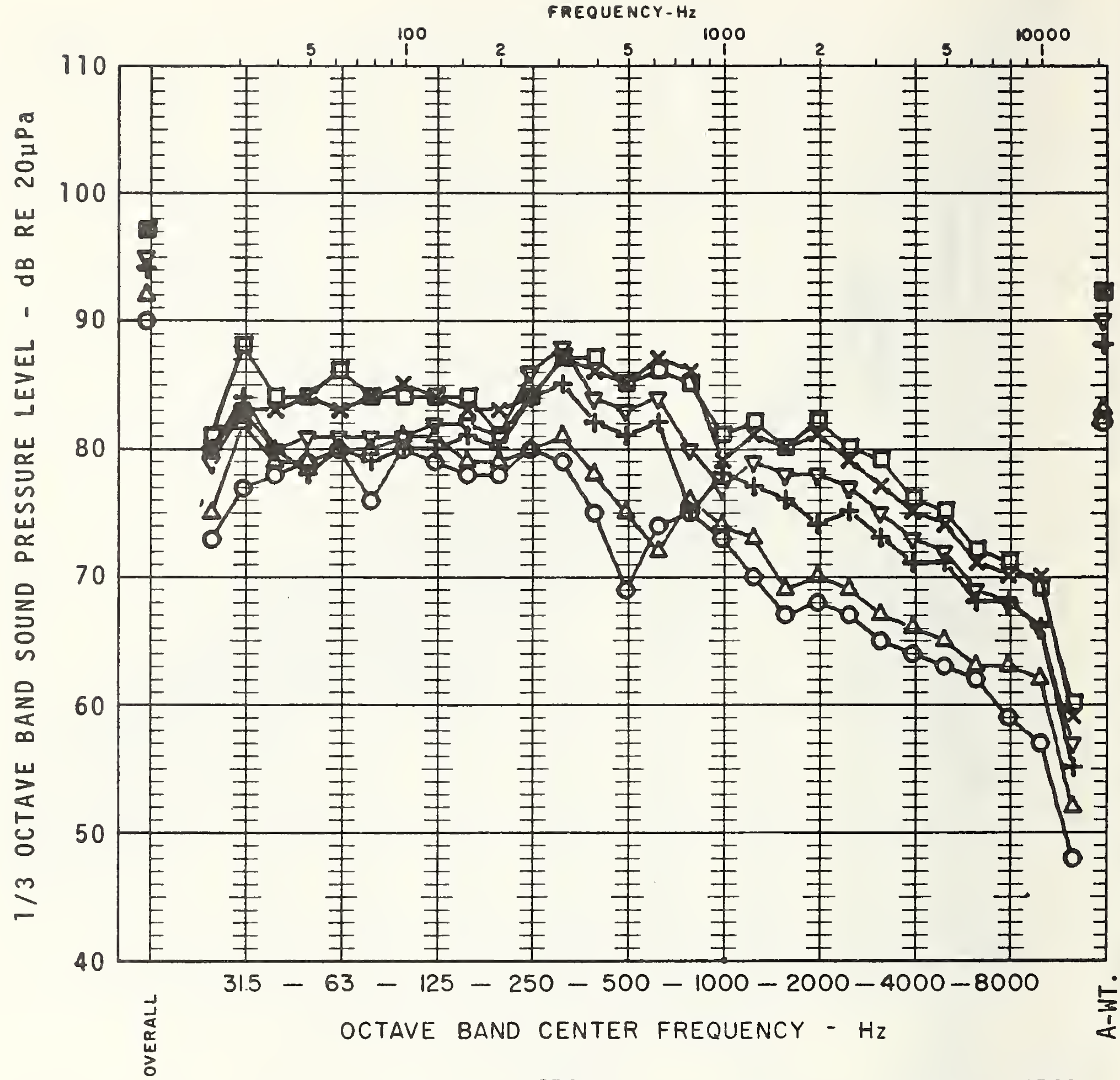


FIGURE B-34. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR AT CENTER - NEW SAB RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×——×	REVERSE	78	△——△	REVERSE	44
+——+	NORMAL	60	▽——▽	NORMAL	67
□——□	REVERSE	76			
○——○	NORMAL	40			

FIGURE B-35. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIB; OCTOBER 14, 1976

WAYSIDE - WORN STANDARD WHEELS

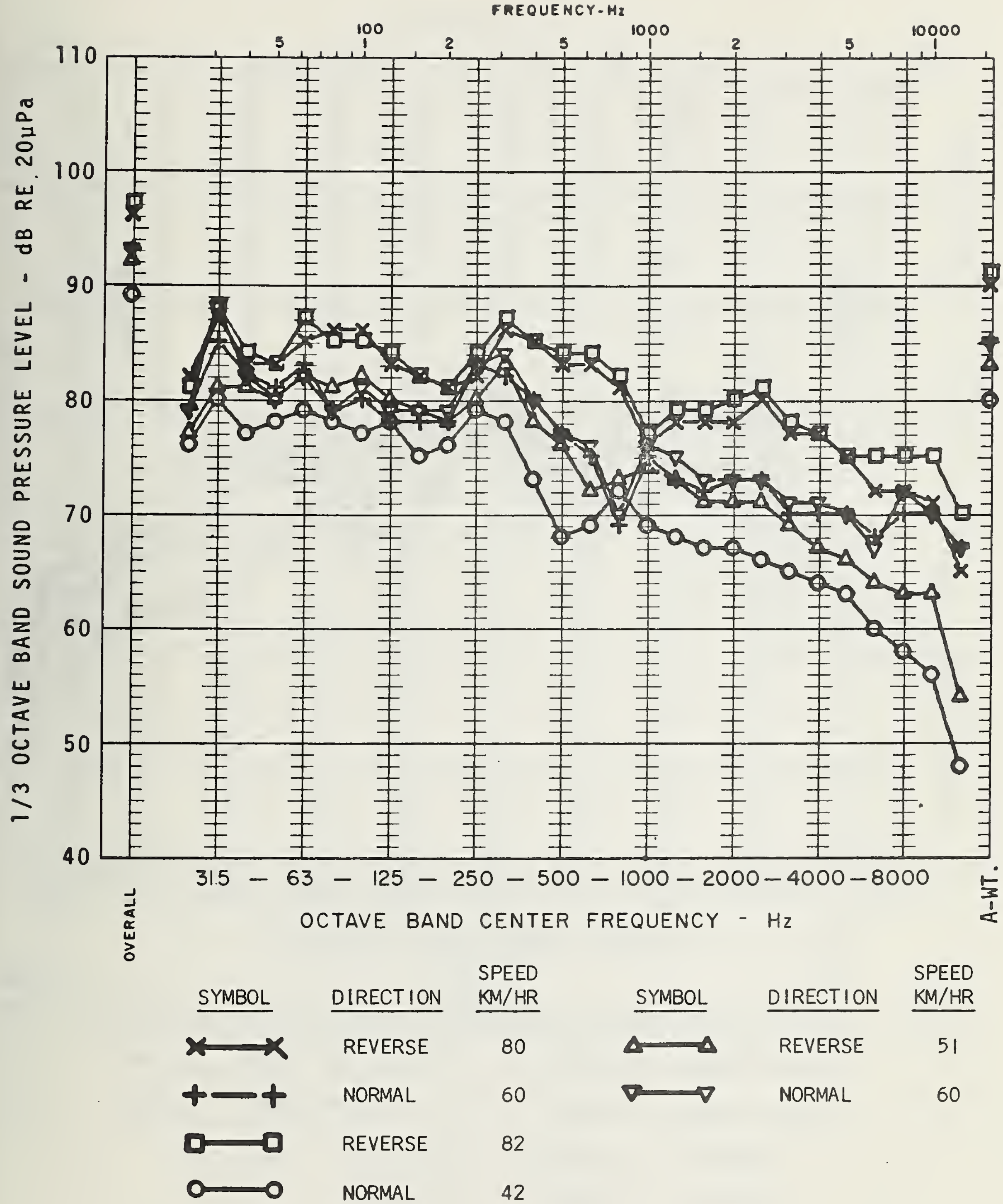
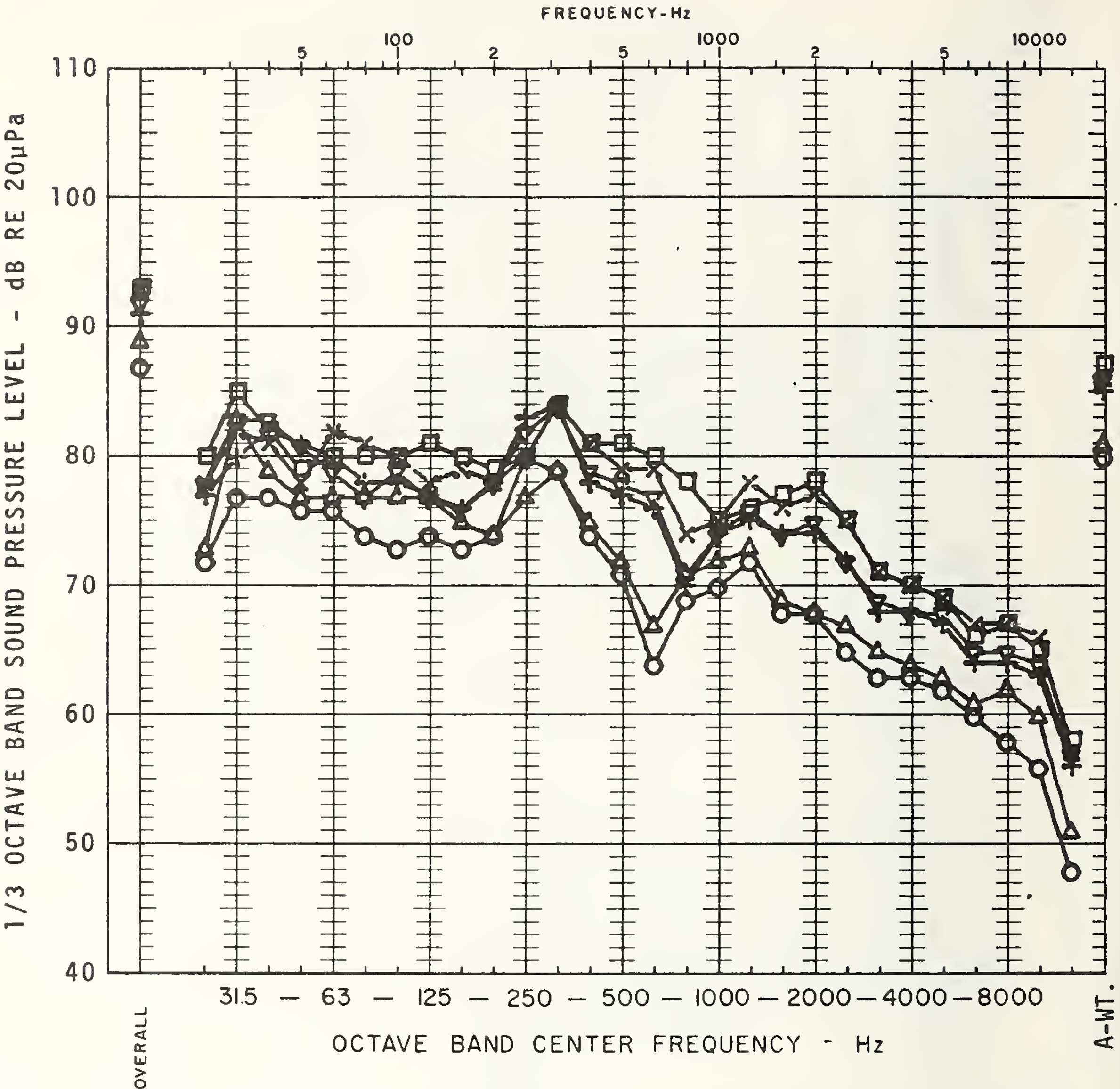


FIGURE B-36. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIB; OCTOBER 14, 1976

WAYSIDE - TRUED STANDARD WHEELS

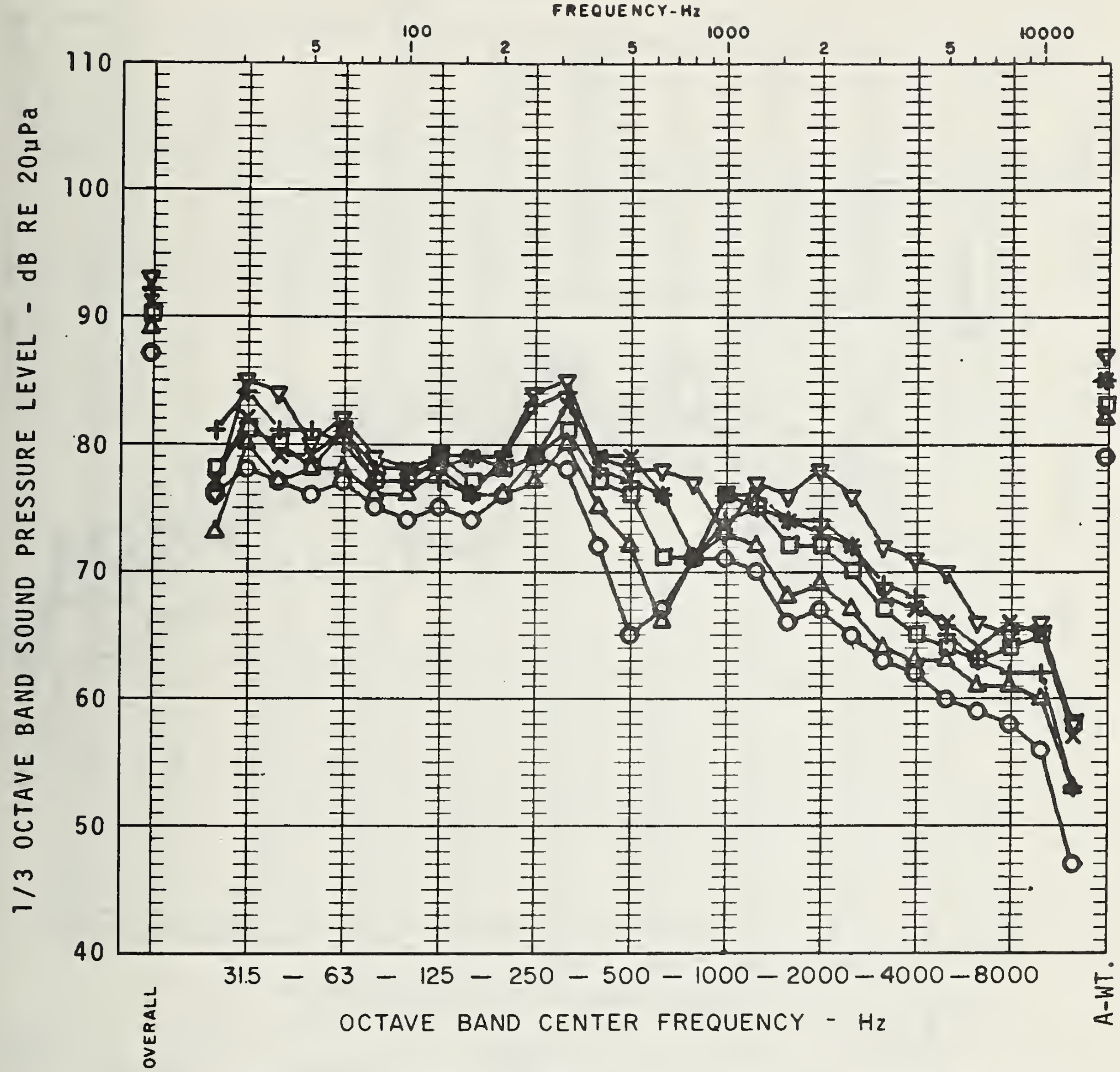


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	69	△—△	REVERSE	46
+—+	NORMAL	64	▽—▽	NORMAL	64
□—□	REVERSE	74			
○—○	NORMAL	46			

FIGURE B-37. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIB; OCTOBER 14, 1976

WAYSIDE - NEW ACOUSTAFLEX RESILIENT WHEELS

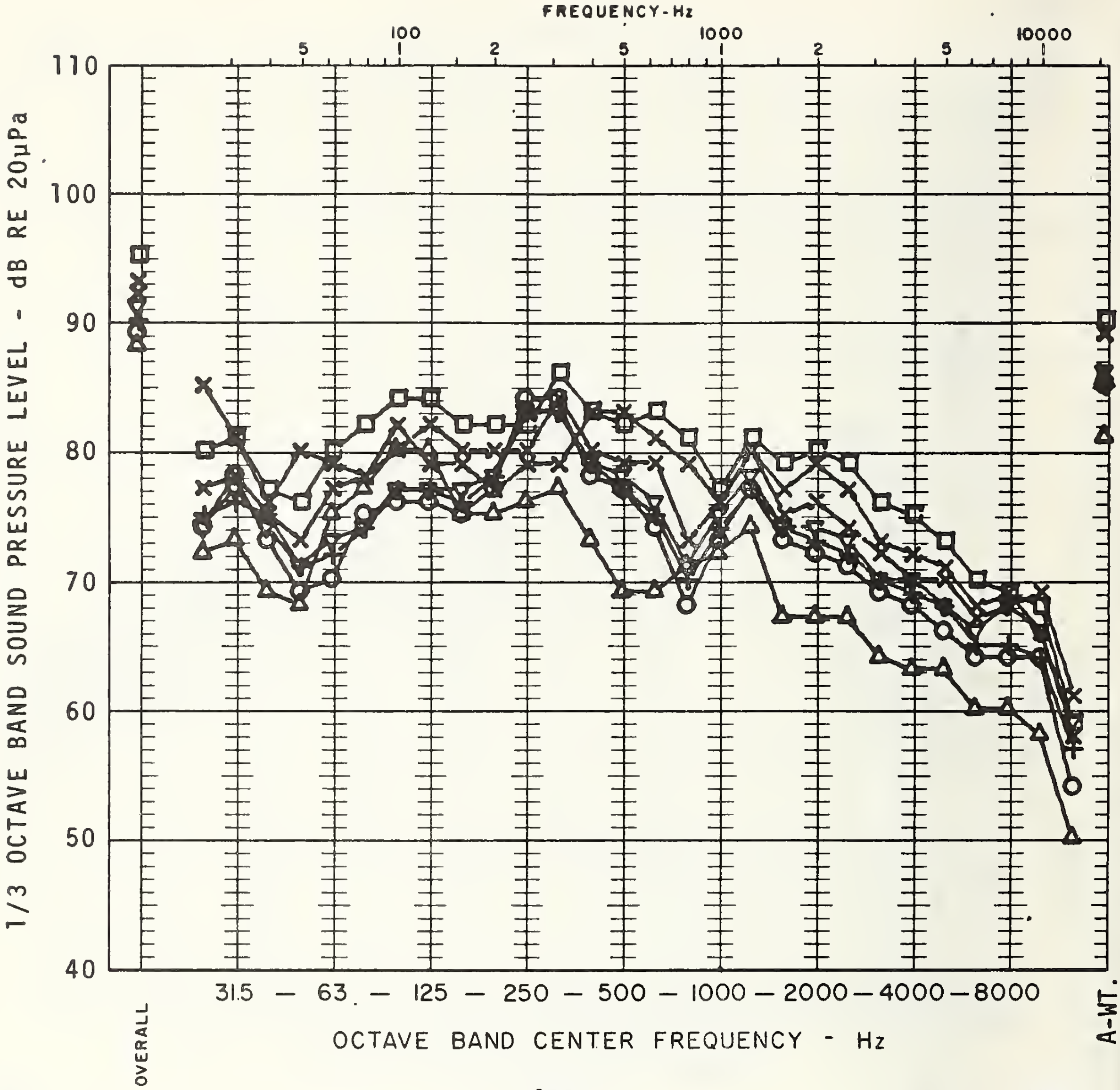


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
X——X	REVERSE	61	△——△	REVERSE	46
+——+	NORMAL	64	▽——▽	NORMAL	74
□——□	REVERSE	54			
O——O	NORMAL	42			

FIGURE B-38. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A

PHASE IIB; OCTOBER 14, 1976

WAYSIDE - NEW PENN BOCHUM RESILIENT WHEELS



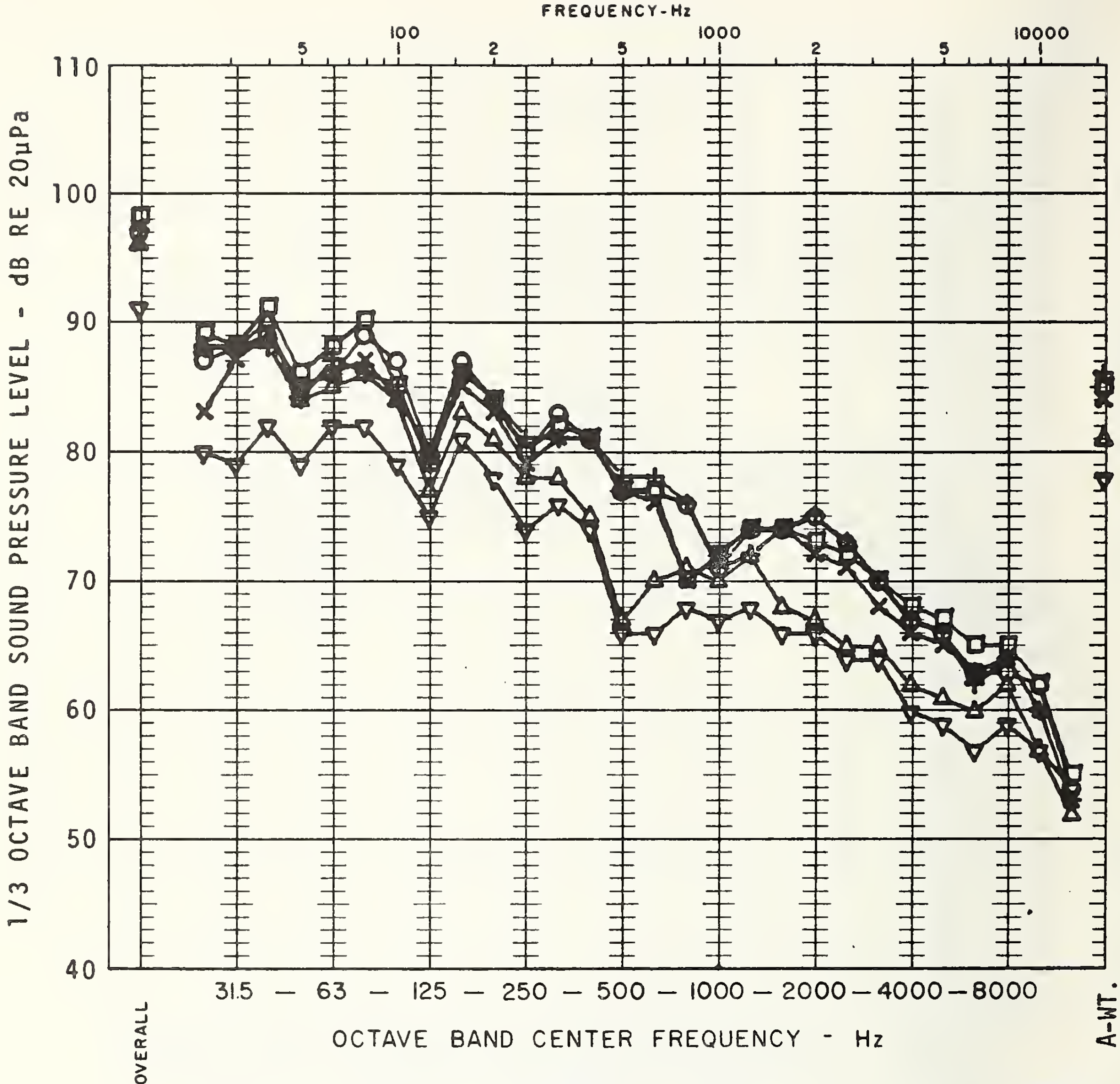
SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	80	△—△	REVERSE	43
+—+	NORMAL	62	▽—▽	NORMAL	63
□—□	REVERSE	81	×—×	REVERSE	65
○—○	NORMAL	60			

FIGURE B-39. BALLAST AND TIE TANGENT-JOINTED TEST TRACK A
PHASE IIB; OCTOBER 14, 1976
WAYSIDE - NEW SAB RESILIENT WHEELS

APPENDIX C

SPECTRA OF MEASUREMENTS ON TEST FROG *

* Spectra include wayside and car interior measurements for worn-standard, trued-standard, Acoustaflex, Bochum and SAB wheels for Test Phase IIB. Notch filter used on all spectra in Appendix C.

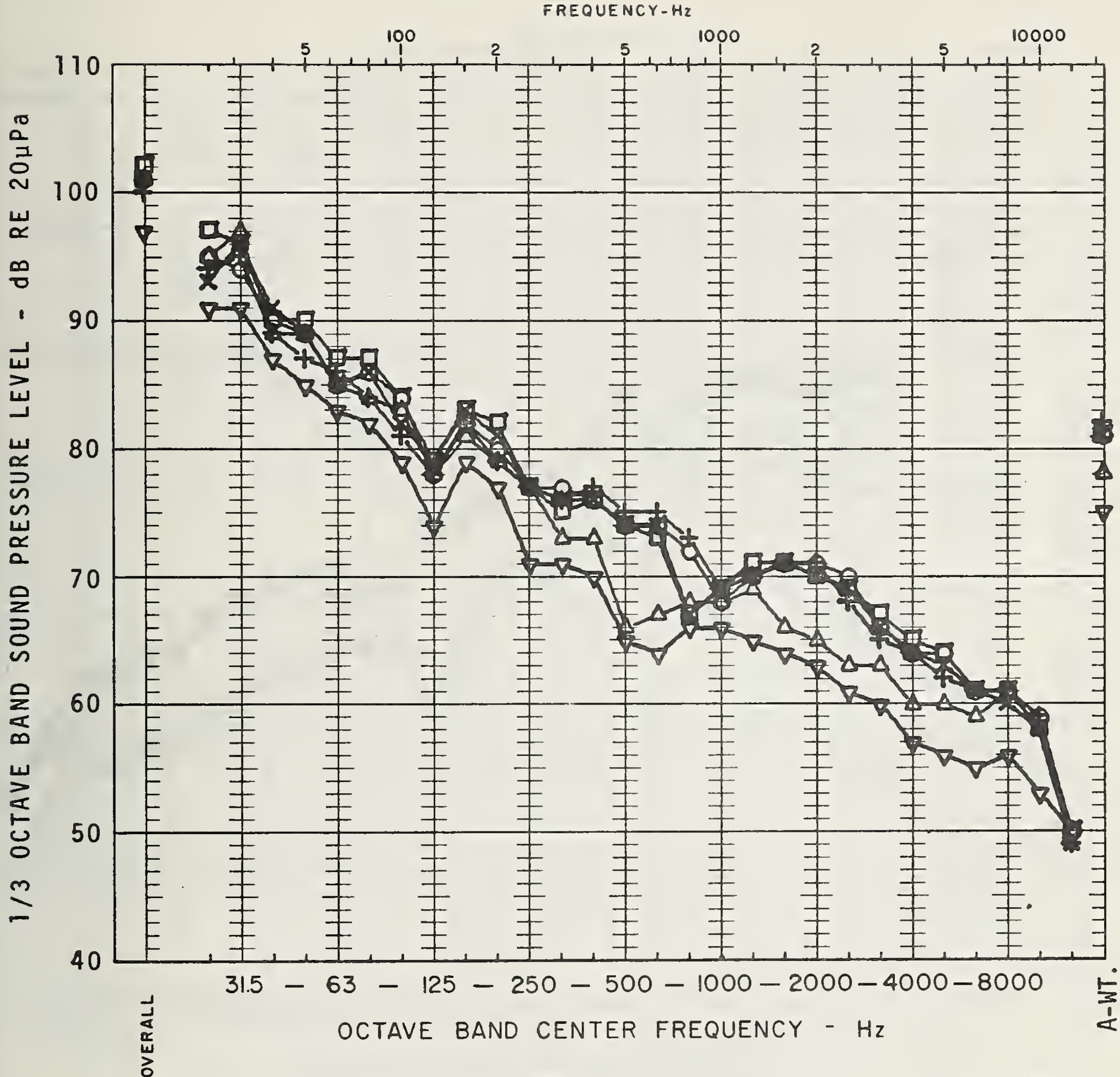


SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	64
+—+	NORMAL	82
□—□	REVERSE	64
○—○	NORMAL	80
△—△	REVERSE	41
▽—▽	NORMAL	42

FIGURE C-1. TEST FROG ON BALLAST AND TIE TRACK

PHASE IIB; OCTOBER 14, 1976

CAR INTERIOR, OVER TRUCK - WORN STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
X——X	REVERSE	64	△——△	REVERSE	41
+——+	NORMAL	82	▽——▽	NORMAL	42
□——□	REVERSE	64			
O——O	NORMAL	80			

FIGURE C-2. TEST FROG ON BALLAST AND TIE TRACK

PHASE IIB; OCTOBER 14, 1976

CAR INTERIOR AT CENTER - WORN STANDARD WHEELS

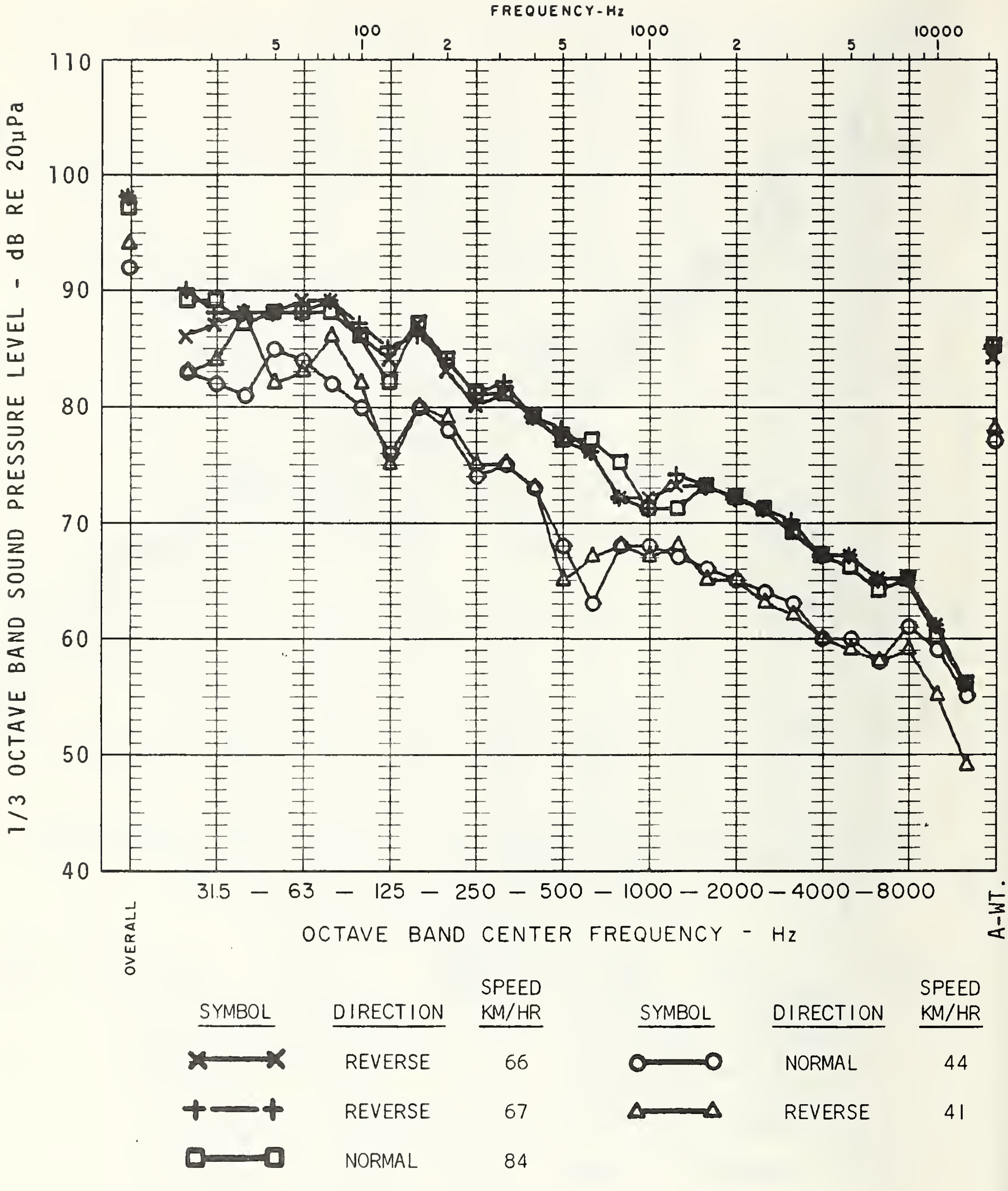
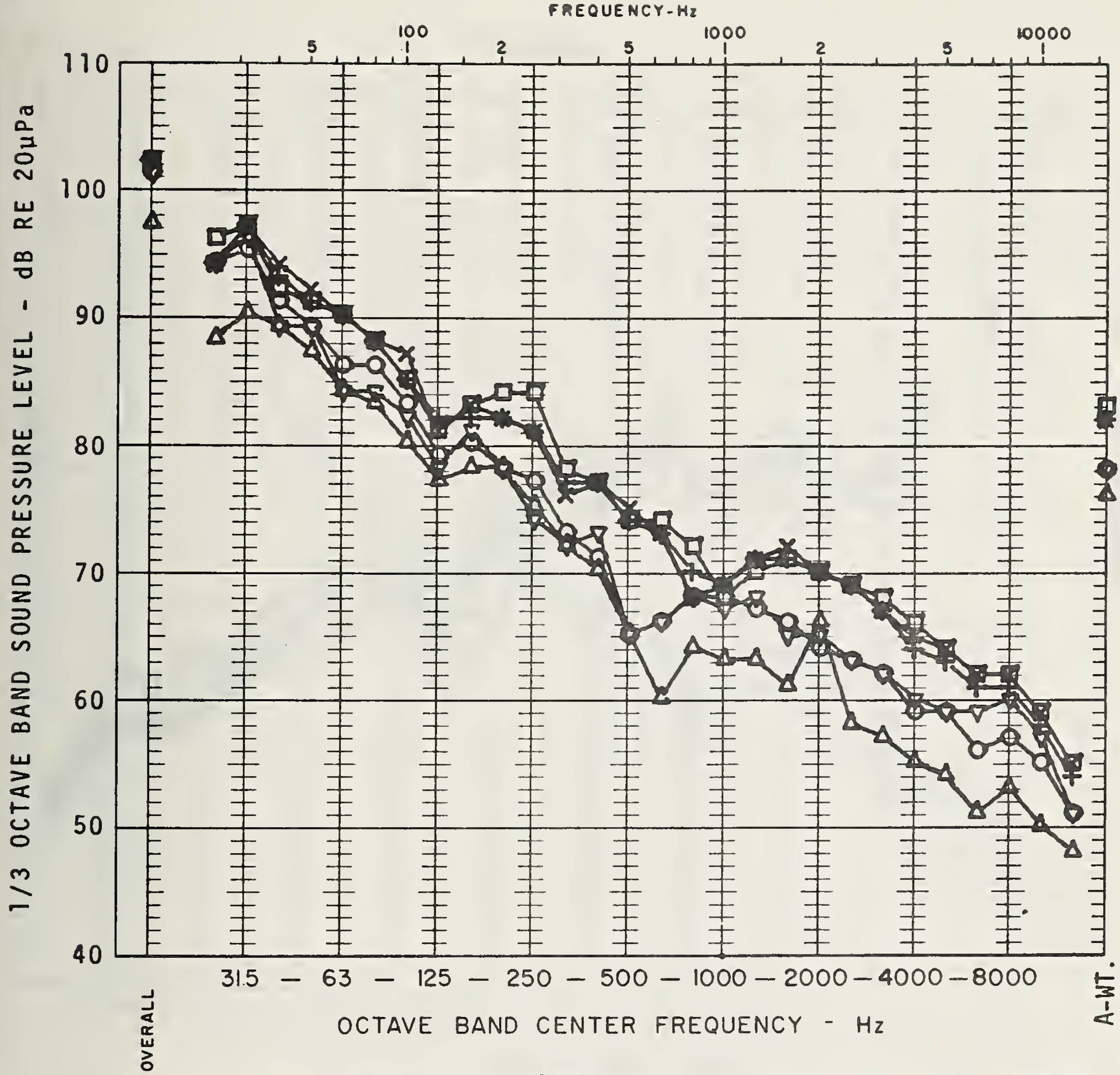


FIGURE C-3. TEST FROG ON BALLAST AND TIE TRACK

PHASE IIB; OCTOBER 14, 1976

CAR INTEROR, OVER TRUCK - TRUED STANDARD WHEELS

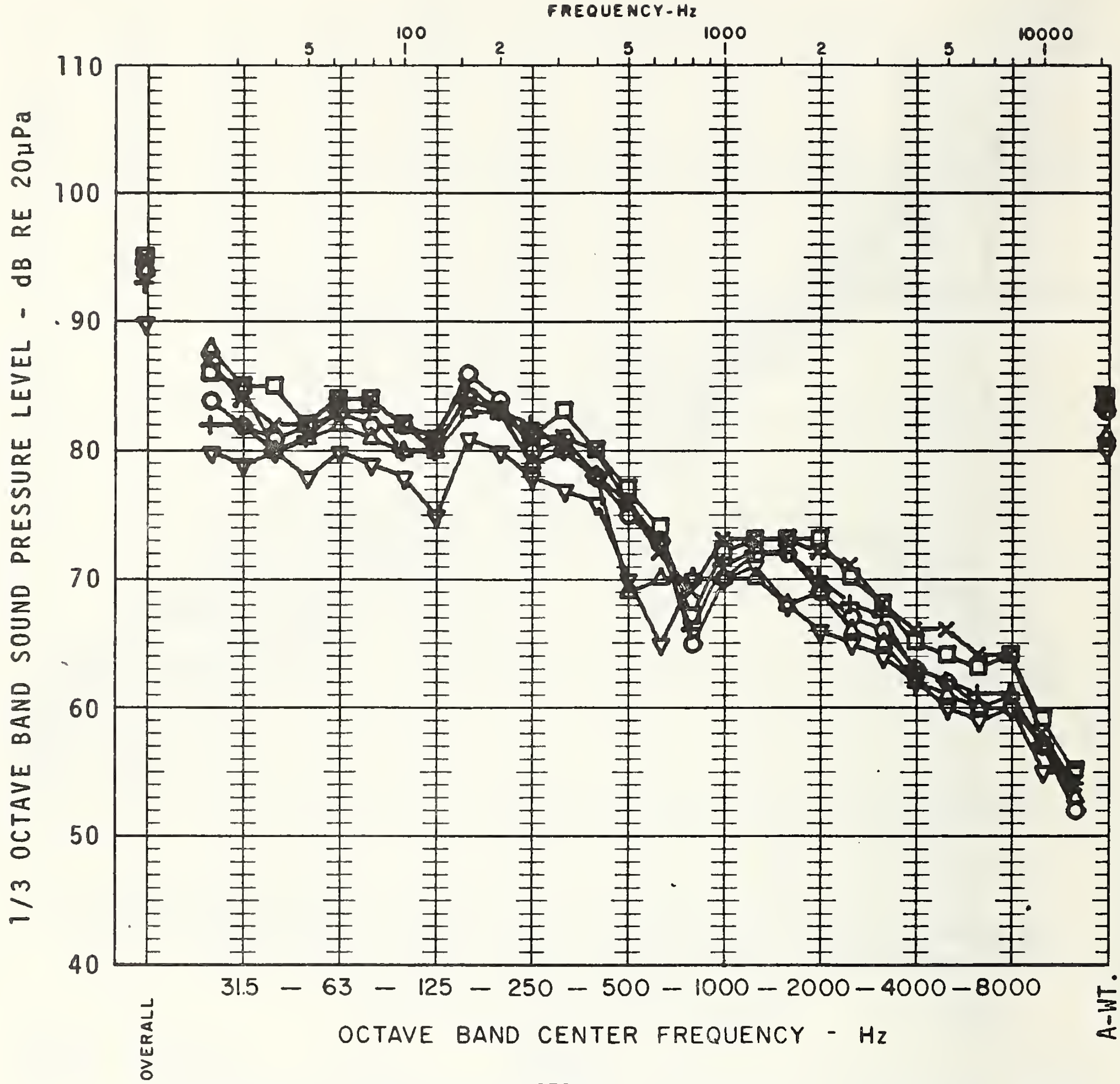


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	66	△—△	NORMAL	44
+—+	REVERSE	67	▽—▽	REVERSE	41
□—□	NORMAL	84			
○—○	REVERSE	41			

FIGURE C-4. TEST FROG ON BALLAST AND TIE TRACK

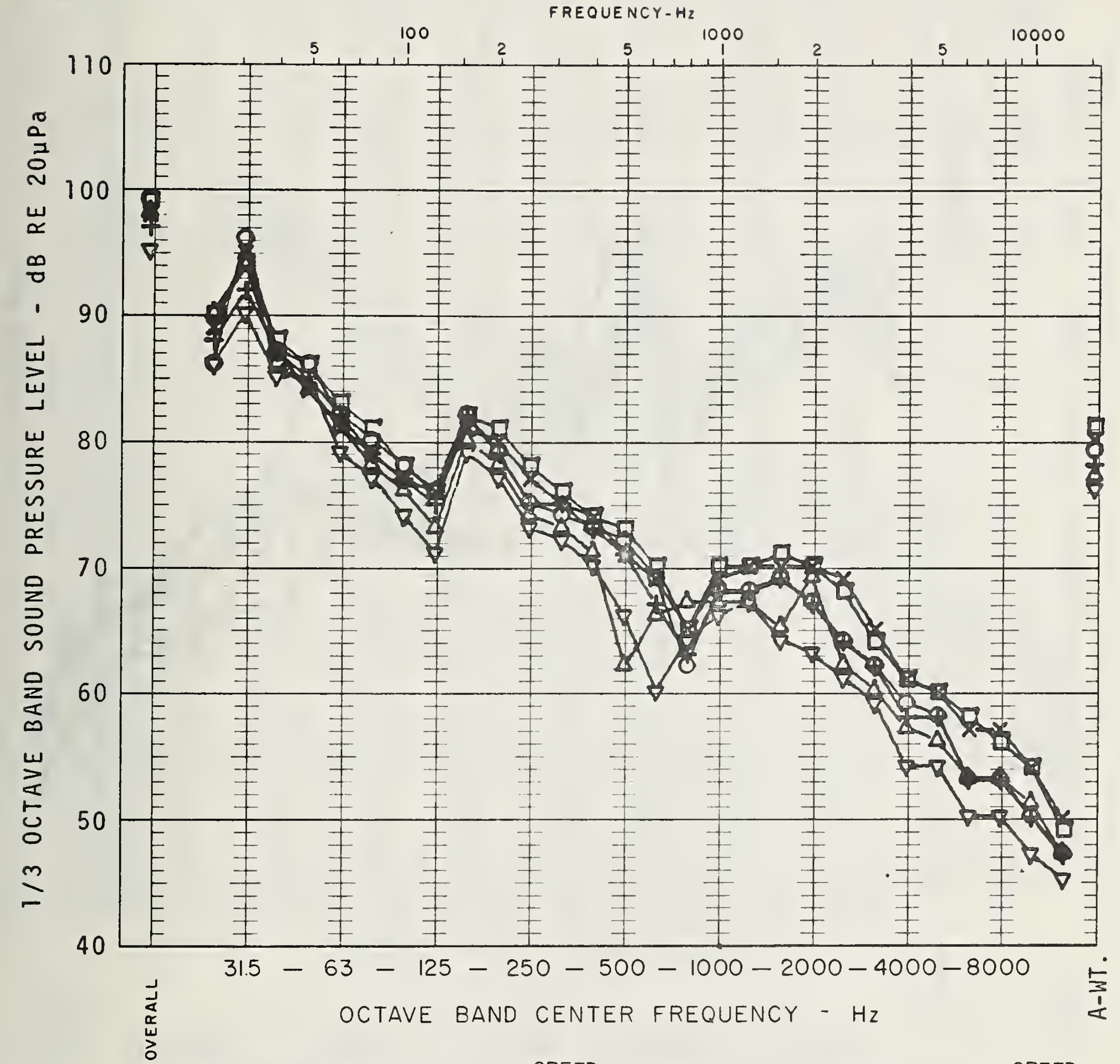
PHASE IIB; OCTOBER 14, 1976

CAR INTERIOR AT CENTER - TRUED STANDARD WHEELS



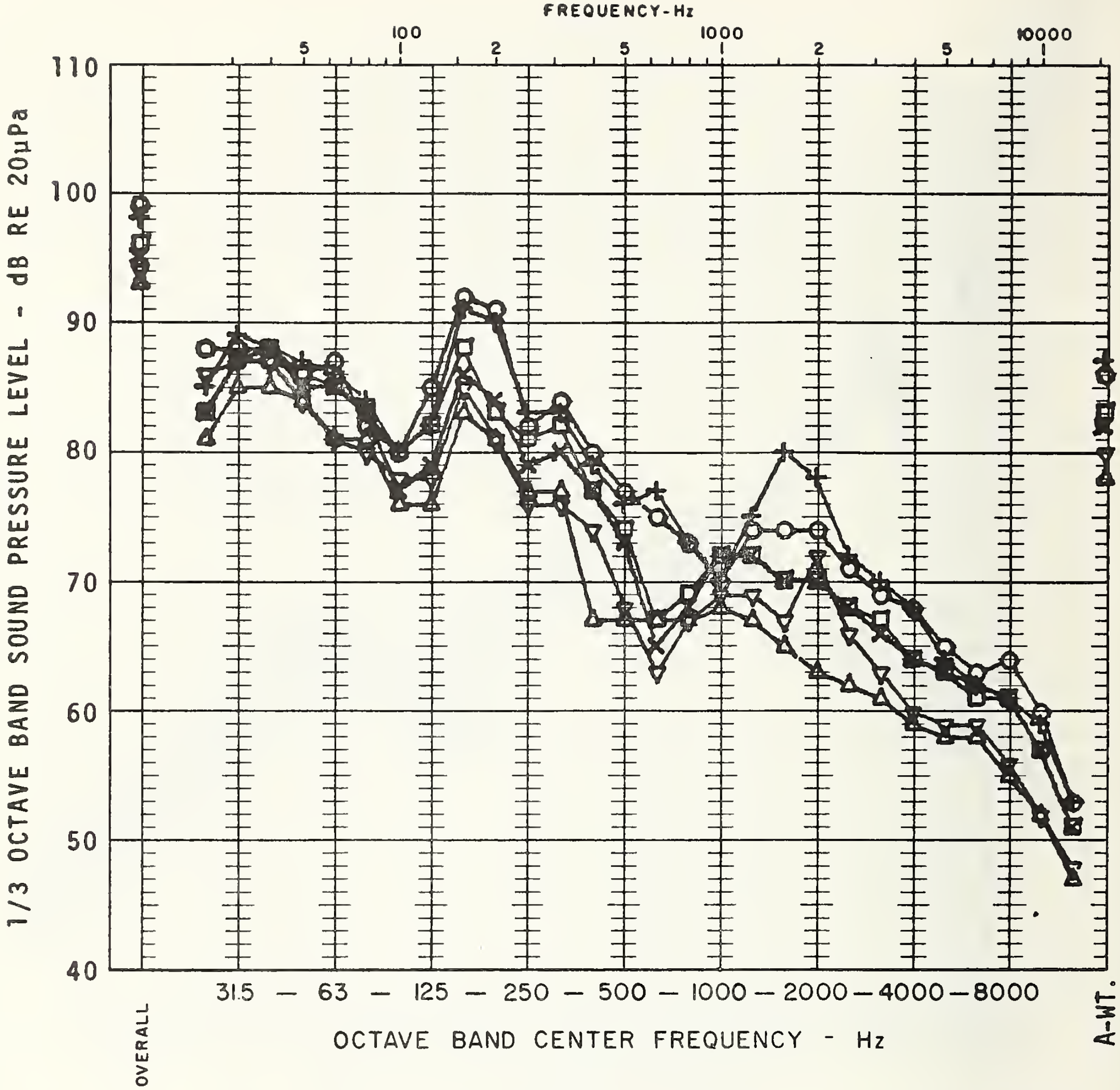
SYMBOL	DIRECTION	SPEED KM/HR
✕—✕	REVERSE	56
+—+	NORMAL	59
□—□	REVERSE	59
○—○	NORMAL	60
△—△	REVERSE	39
▽—▽	NORMAL	44

FIGURE C-5. TEST FROG ON BALLAST AND TIE TRACK
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR, OVER TRUCK - NEW RESILIENT ACOUSTAFLEX WHEELS



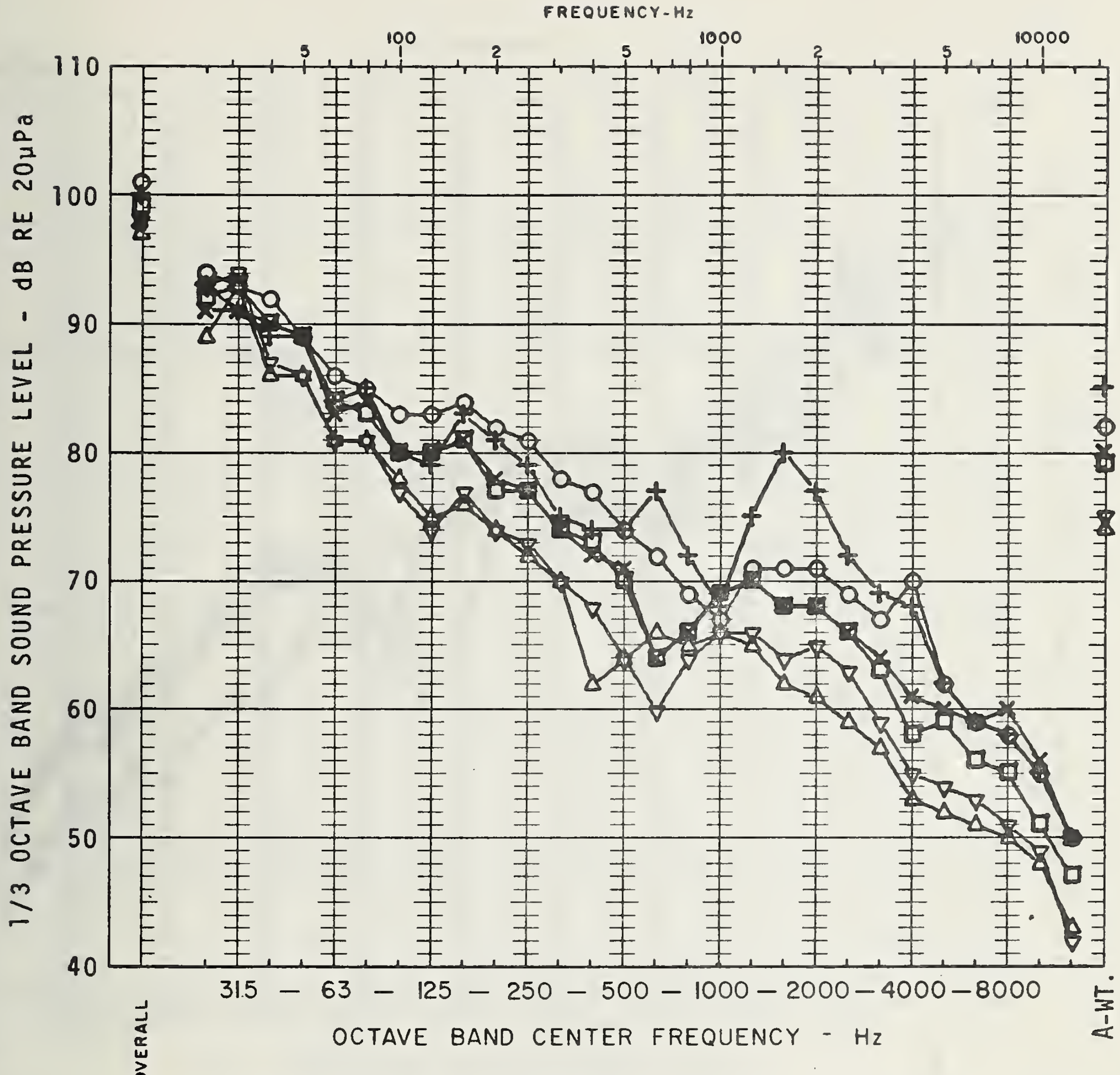
SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	56	△—△	REVERSE	39
+—+	NORMAL	59	▽—▽	NORMAL	44
□—□	REVERSE	59			
○—○	NORMAL	60			

FIGURE C-6. TEST FROG ON BALLAST AND TIE TRACK
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR AT CENTER - NEW RESILIENT ACOUSTAFLEX WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
X———X	REVERSE	51	△———△	REVERSE	32
+———+	NORMAL	73	▽———▽	NORMAL	
□———□	REVERSE	52			
○———○	NORMAL	73			

FIGURE C-7. TEST FROG ON BALLAST AND TIE TRACK
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR, OVER TRUCK - NEW PENN BOCHUM RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	51	△—△	REVERSE	32
+—+	NORMAL	73	▽—▽	NORMAL	44
□—□	REVERSE	52			
○—○	NORMAL	73			

FIGURE C-8. TEST FROG ON BALLAST AND TIE TRACK
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR AT CENTER - NEW PENN BOCHUM RESILIENT WHEELS

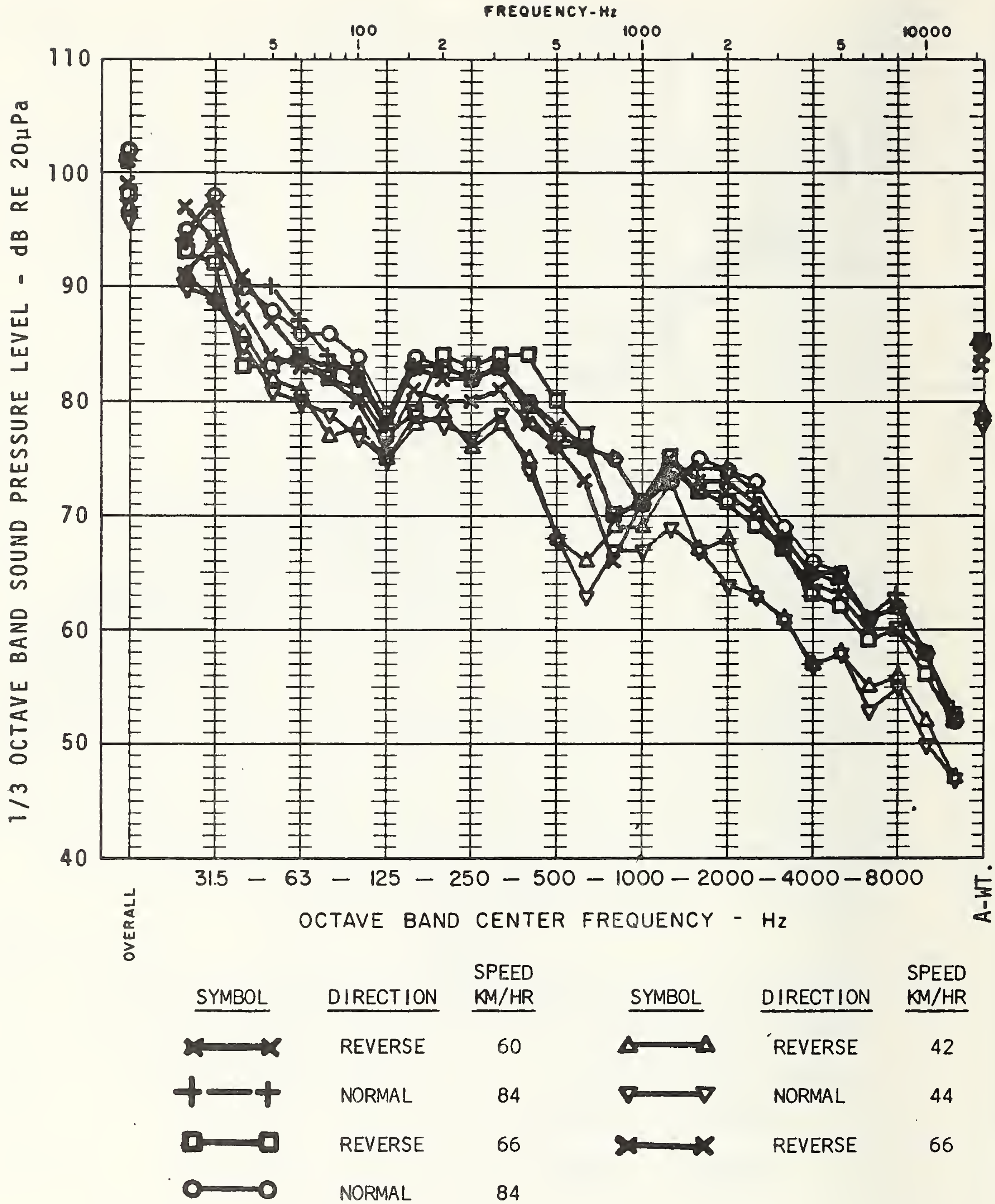
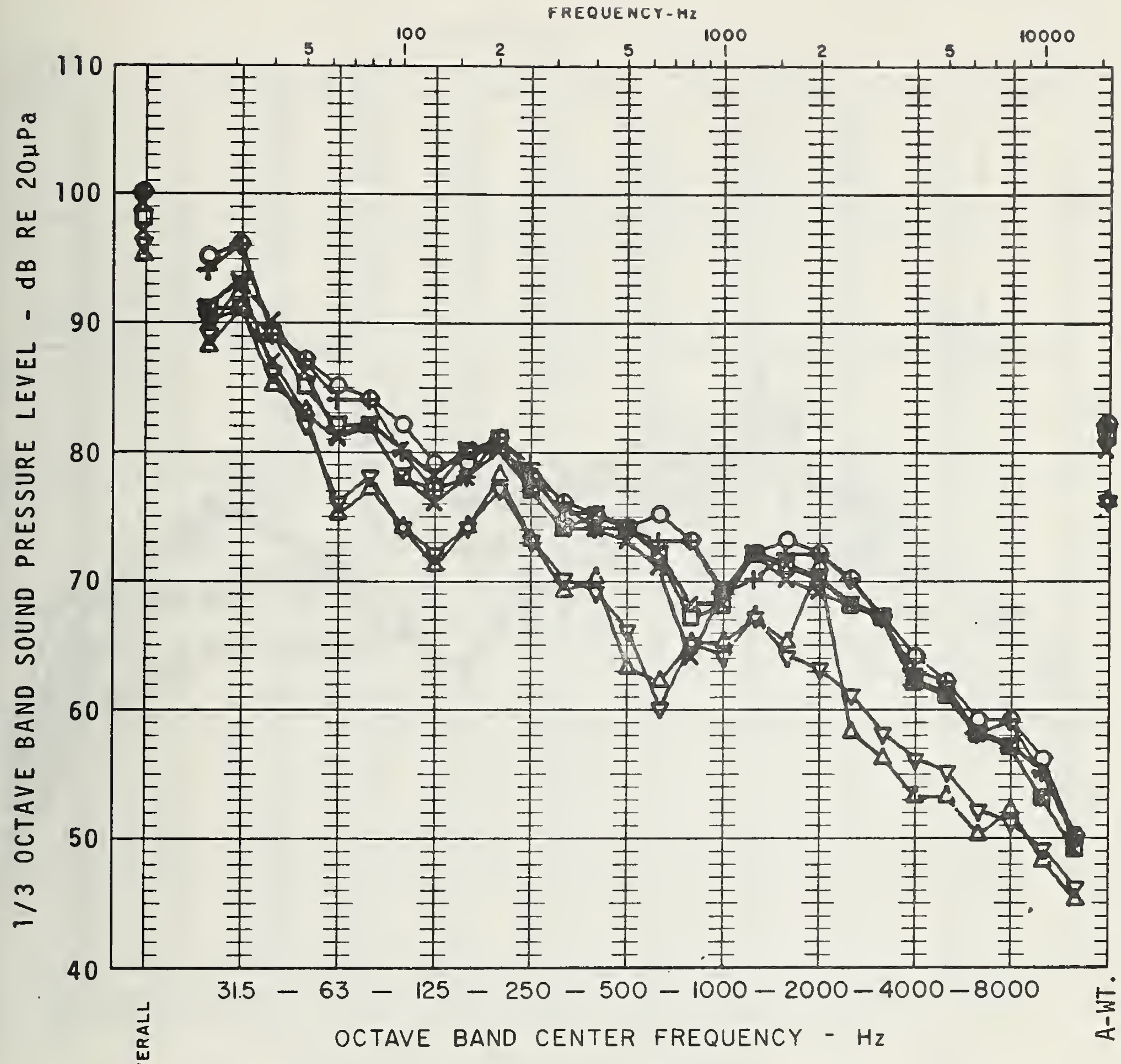
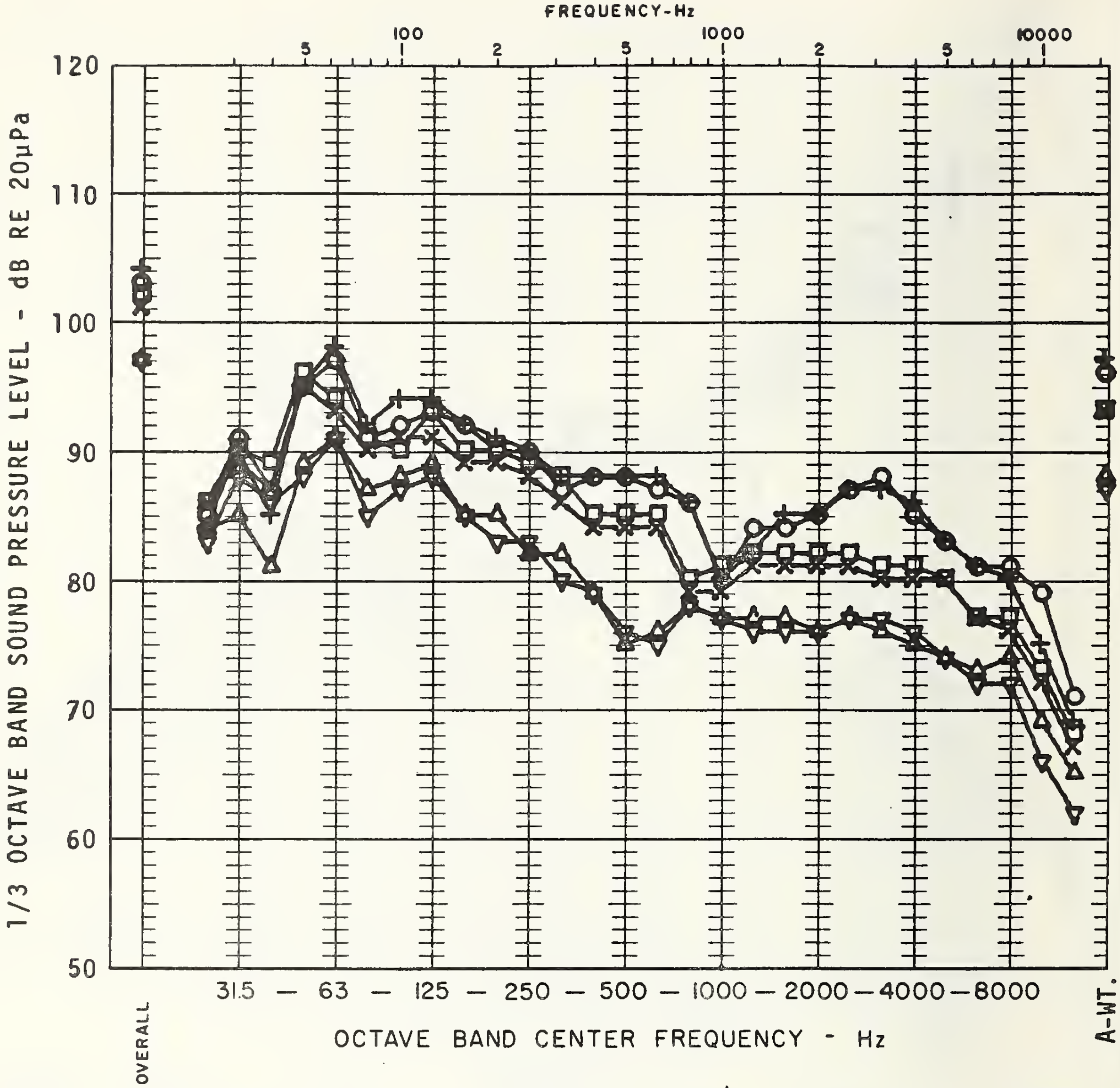


FIGURE C-9. TEST FROG ON BALLAST AND TIE TRACK
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR, OVER TRUCK - NEW SAB RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
✕—✕	REVERSE	84	△—△	REVERSE	42
+—+	NORMAL	84	▽—▽	NORMAL	44
□—□	REVERSE	66	✕—✕	REVERSE	66
○—○	NORMAL	84			

FIGURE C-10. TEST FROG ON BALLAST AND TIE TRACK
PHASE IIB; OCTOBER 14, 1976
CAR INTERIOR AT CENTER - NEW SAB RESILIENT WHEELS

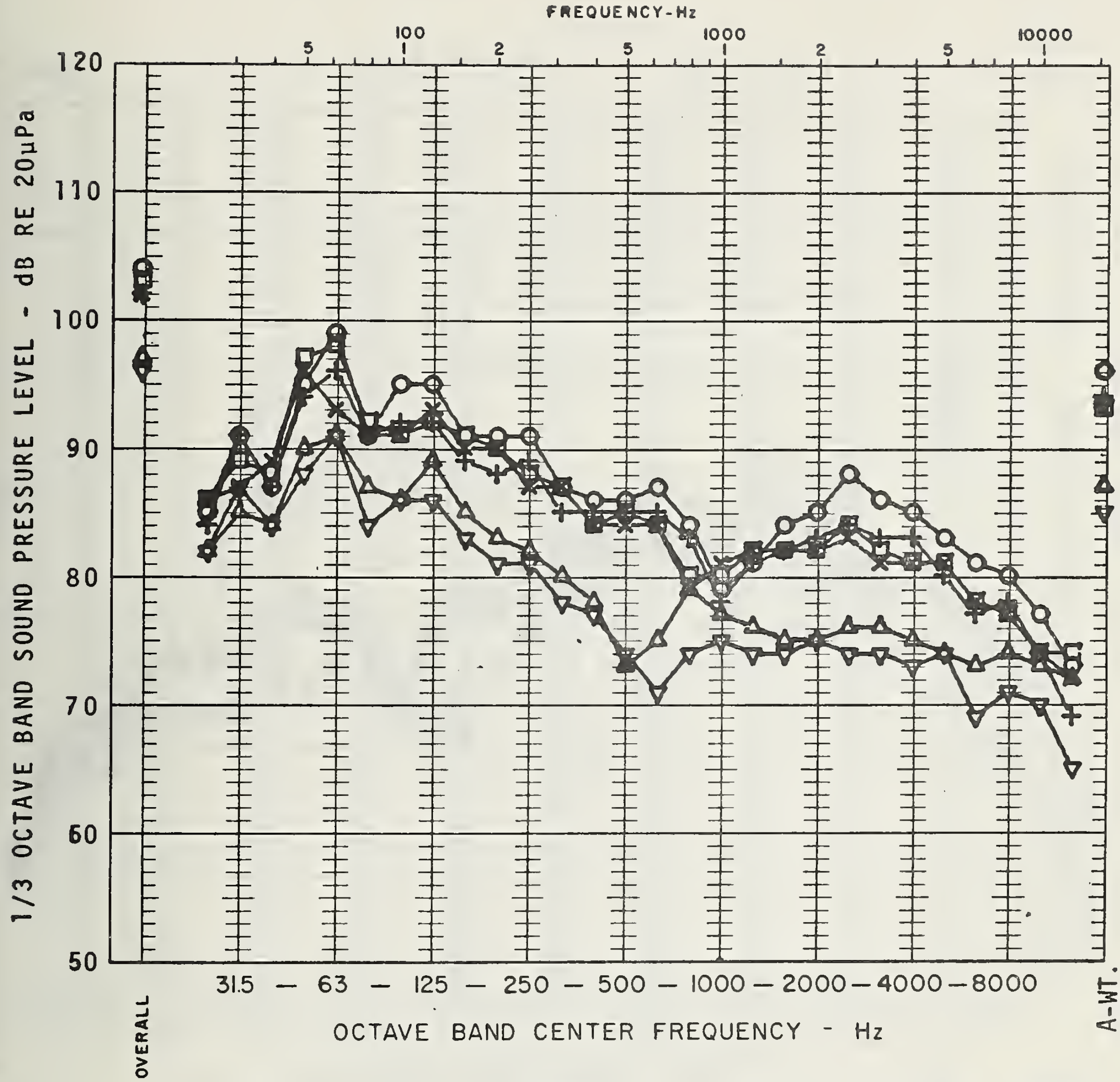


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	64	△—△	REVERSE	41
+—+	NORMAL	82	▽—▽	NORMAL	42
□—□	REVERSE	64			
○—○	NORMAL	80			

FIGURE C-11. TEST FROG ON BALLAST AND TIE TRACK

PHASE IIB; OCTOBER 14, 1976

WAYSIDE - WORN STANDARD WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	66	△—△	REVERSE	41
+—+	NORMAL	83	▽—▽	NORMAL	44
□—□	REVERSE	67			
○—○	NORMAL	84			

FIGURE C-12. TEST FROG ON BALLAST AND TIE TRACK

PHASE IIB; OCTOBER 14, 1976

WAYSIDE - TRUED STANDARD WHEELS

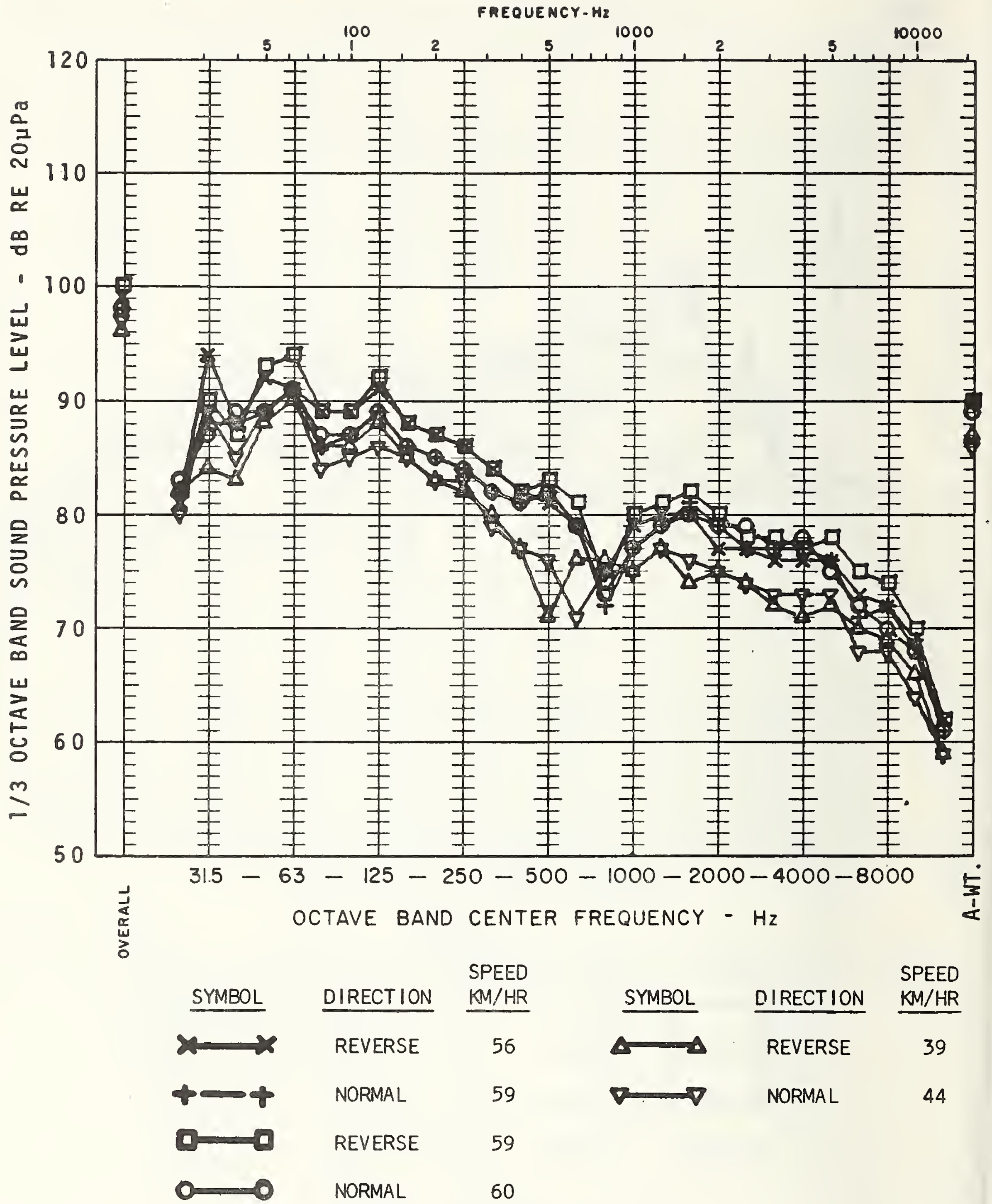
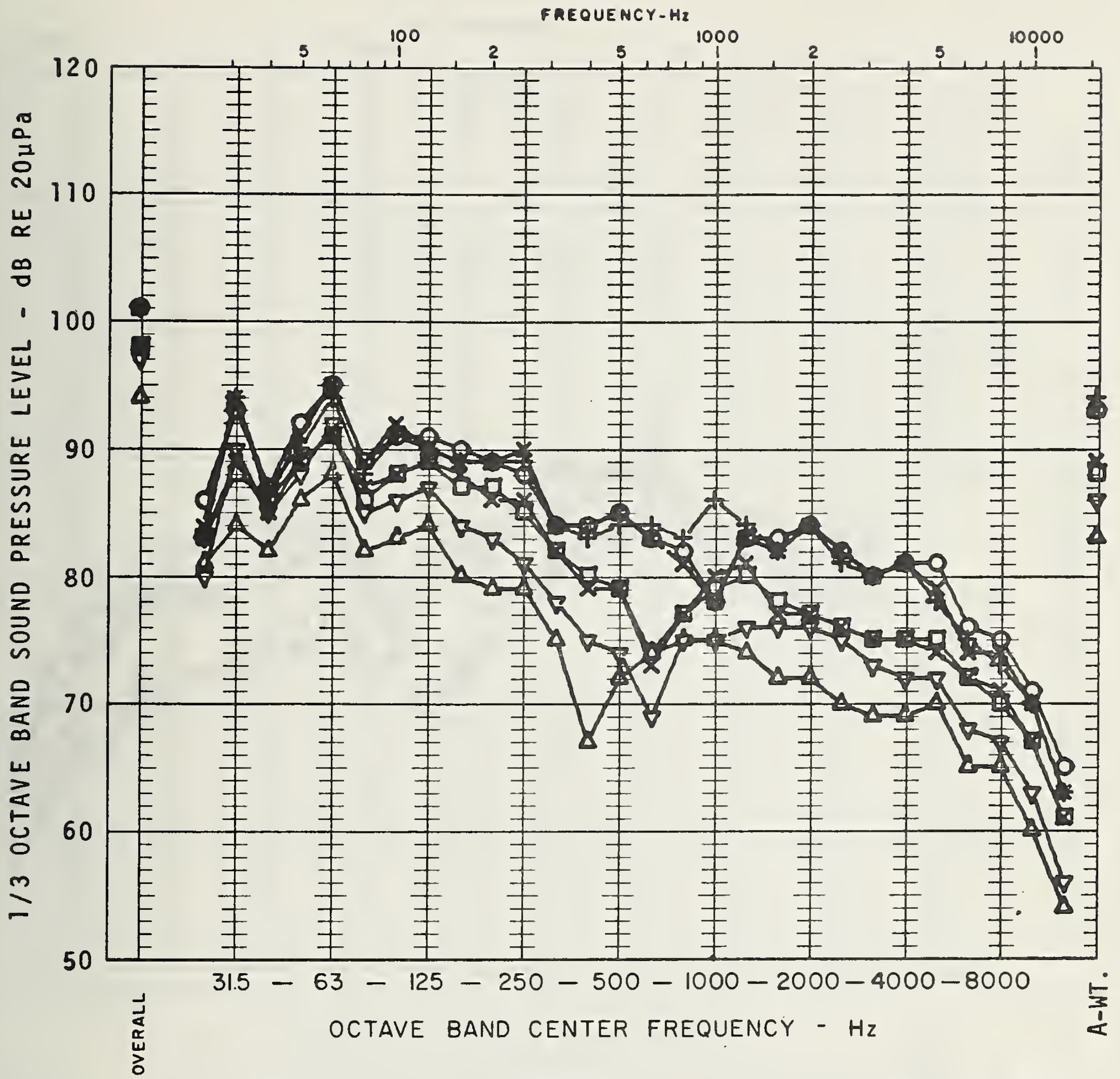


FIGURE C-13. TEST FROG ON BALLAST AND TIE TRACK

PHASE IIB; OCTOBER 14, 1976

WAYSIDE - NEW RESILIENT ACOUSTAFLEX WHEELS

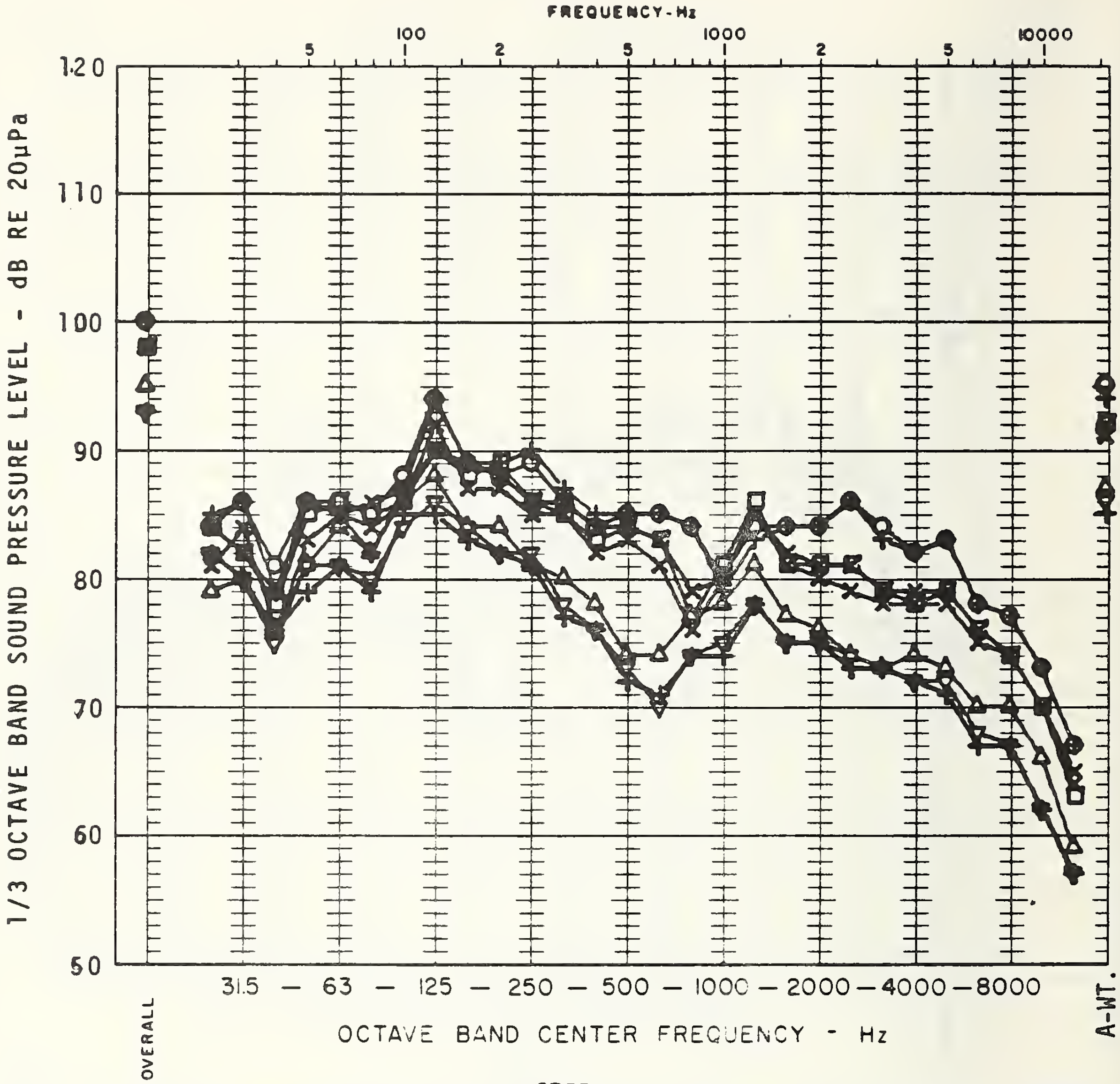


SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
×—×	REVERSE	51	△—△	REVERSE	32
+—+	NORMAL	73	▽—▽	NORMAL	44
□—□	REVERSE	52	×—×	NORMAL	73
○—○	NORMAL	73			

FIGURE C-14. TEST FROG ON BALLAST AND TIE TRACK

PHASE IIB; OCTOBER 14, 1976

WAYSIDE - NEW PENN BOCHUM RESILIENT WHEELS



SYMBOL	DIRECTION	SPEED KM/HR	SYMBOL	DIRECTION	SPEED KM/HR
✕—✕	REVERSE	60	△—△	REVERSE	42
+—+	NORMAL	84	▽—▽	NORMAL	44
□—□	REVERSE	66	✕—✕	REVERSE	66
○—○	NORMAL	84	+—+	NORMAL	43

FIGURE C-15. TEST FROG ON BALLAST AND TIE TRACK

PHASE IIB; OCTOBER 14, 1976

WAYSIDE - NEW SAB RESILIENT WHEELS

APPENDIX D

WHEEL SQUEAL SPECTRA*

* Spectra include wayside measurements for worn-standard and trued-standard wheels for Test Phase IC; wayside measurements for Acoustaflex, Bochum and SAB wheels for Test Phase IIA; and energy averages of all wayside and car interior samples of worn-standard and new-trued-standard wheels for Test Phases IA, IB & IC. Notch filter was not used on the spectra in Appendix D.

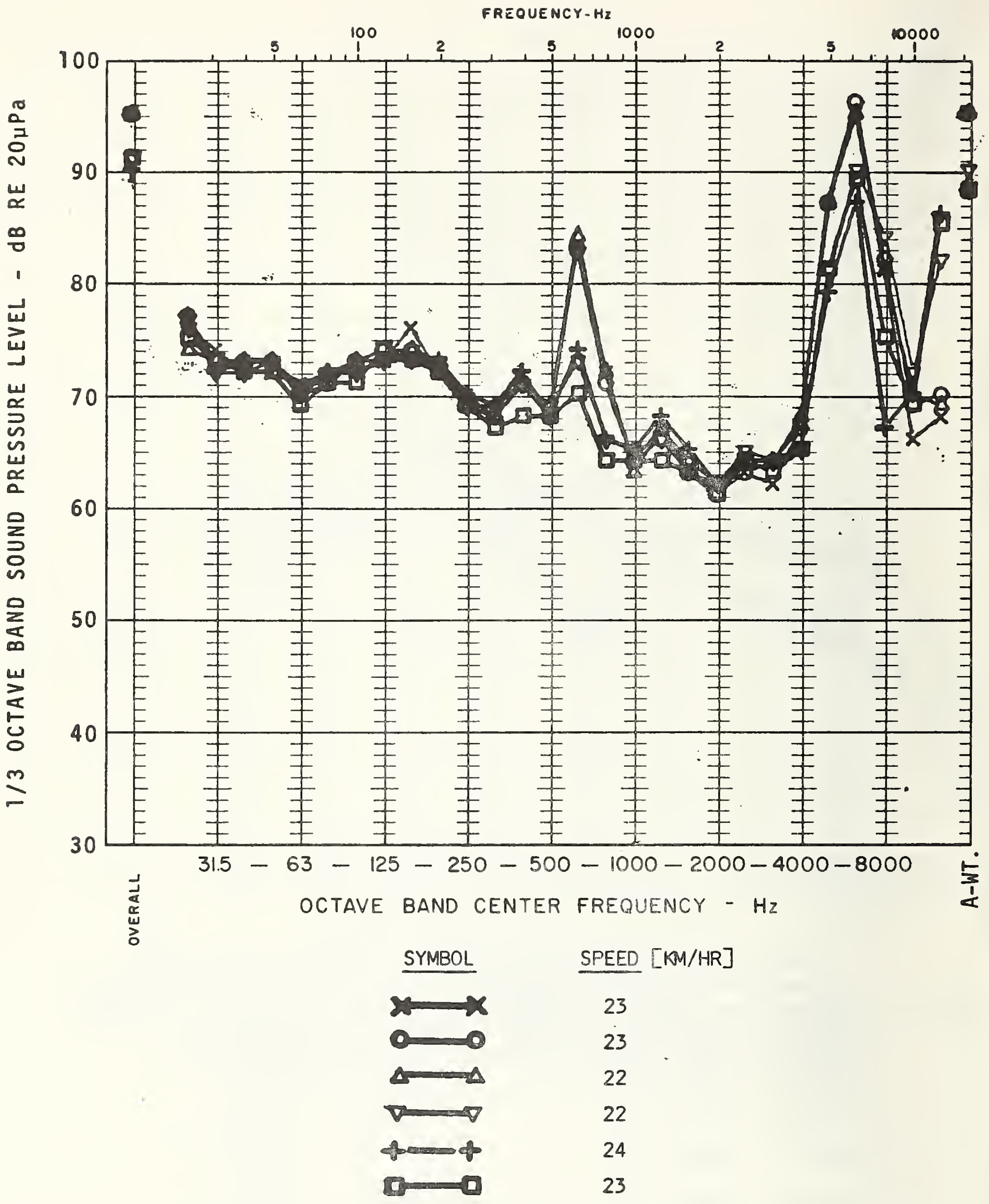


FIGURE D-1. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IC; SEPTEMBER 1, 1976
CONTROL TRACK, WAYSIDE - WORN STANDARD WHEELS

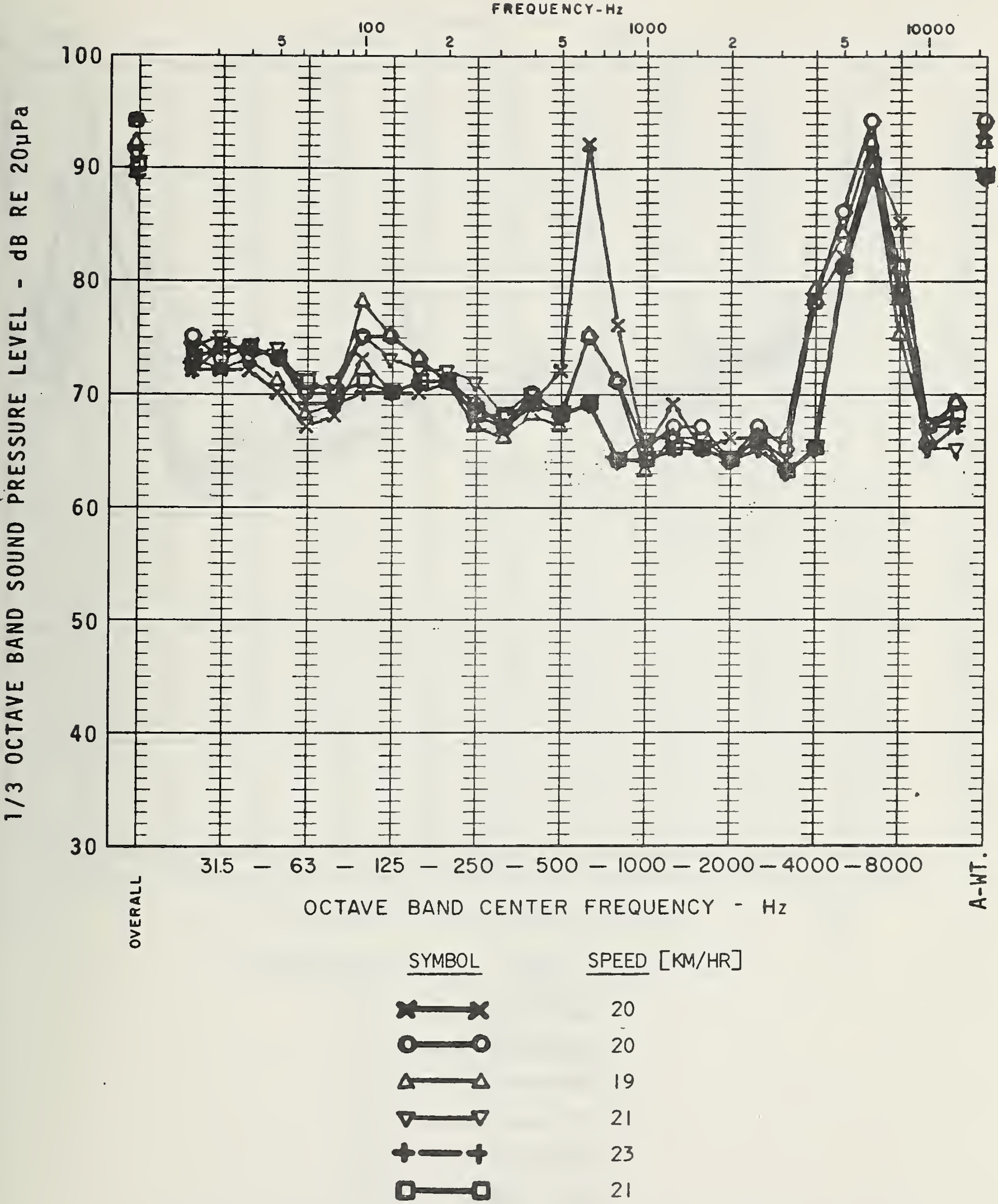


FIGURE D-2. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IC; SEPTEMBER 1, 1976
TEST TRACK, WAYSIDE - WORN STANDARD WHEELS

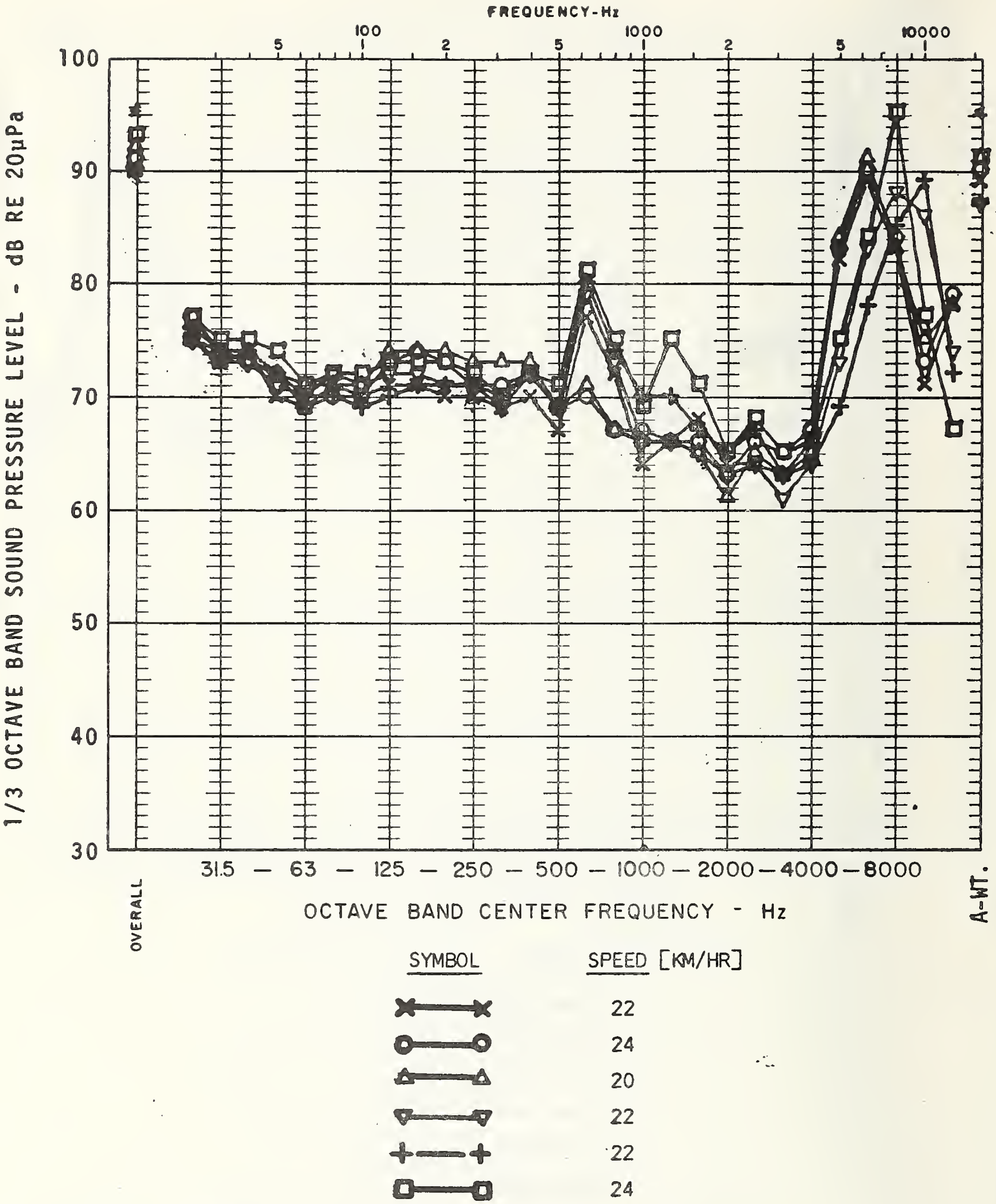


FIGURE D-3. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IC; SEPTEMBER 1, 1976
CONTROL TRACK, WAYSIDE - TRUED STANDARD WHEELS

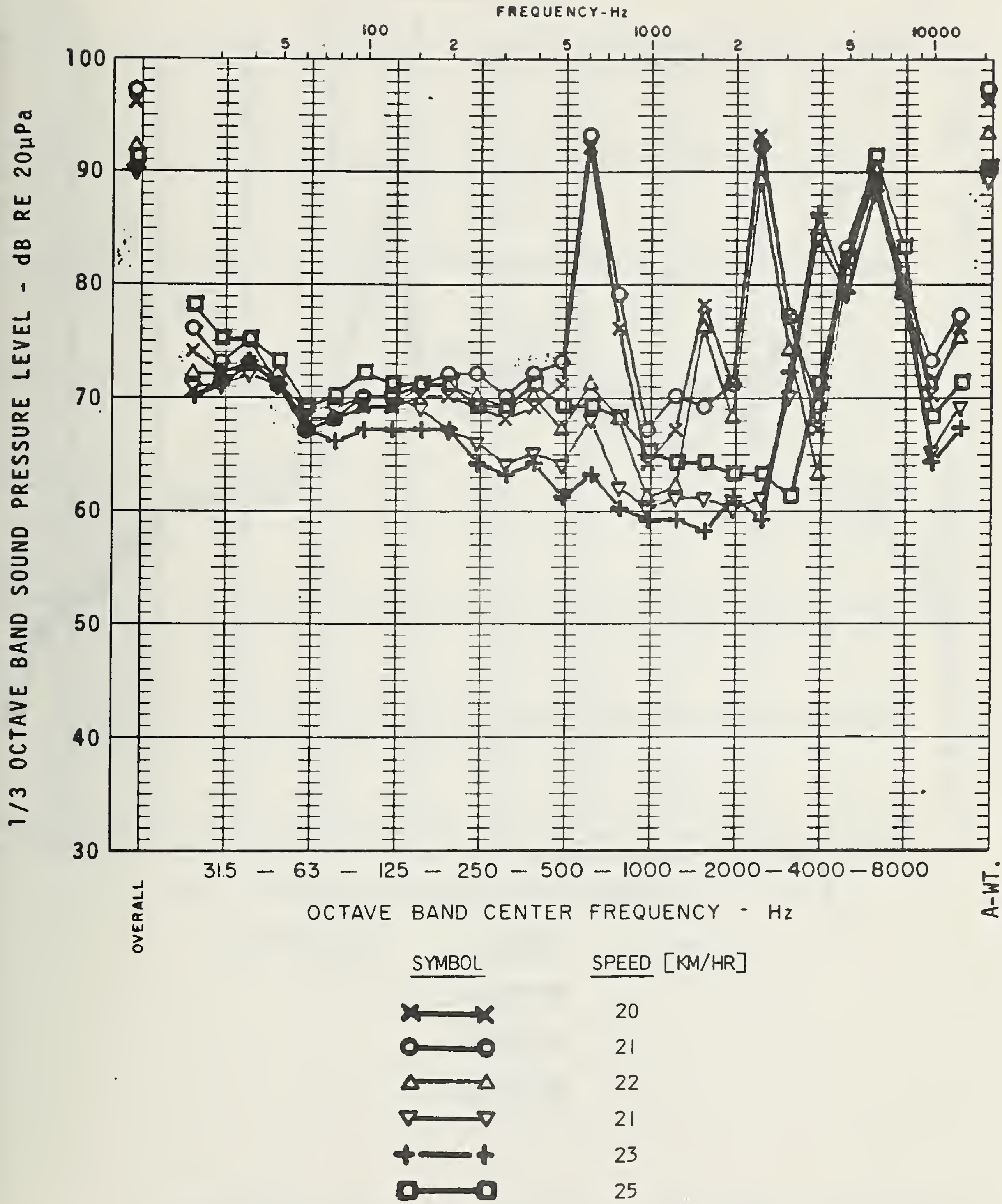


FIGURE D-4. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IC; SEPTEMBER 1, 1976
TEST TRACK, WAYSIDE - TRUED STANDARD WHEELS

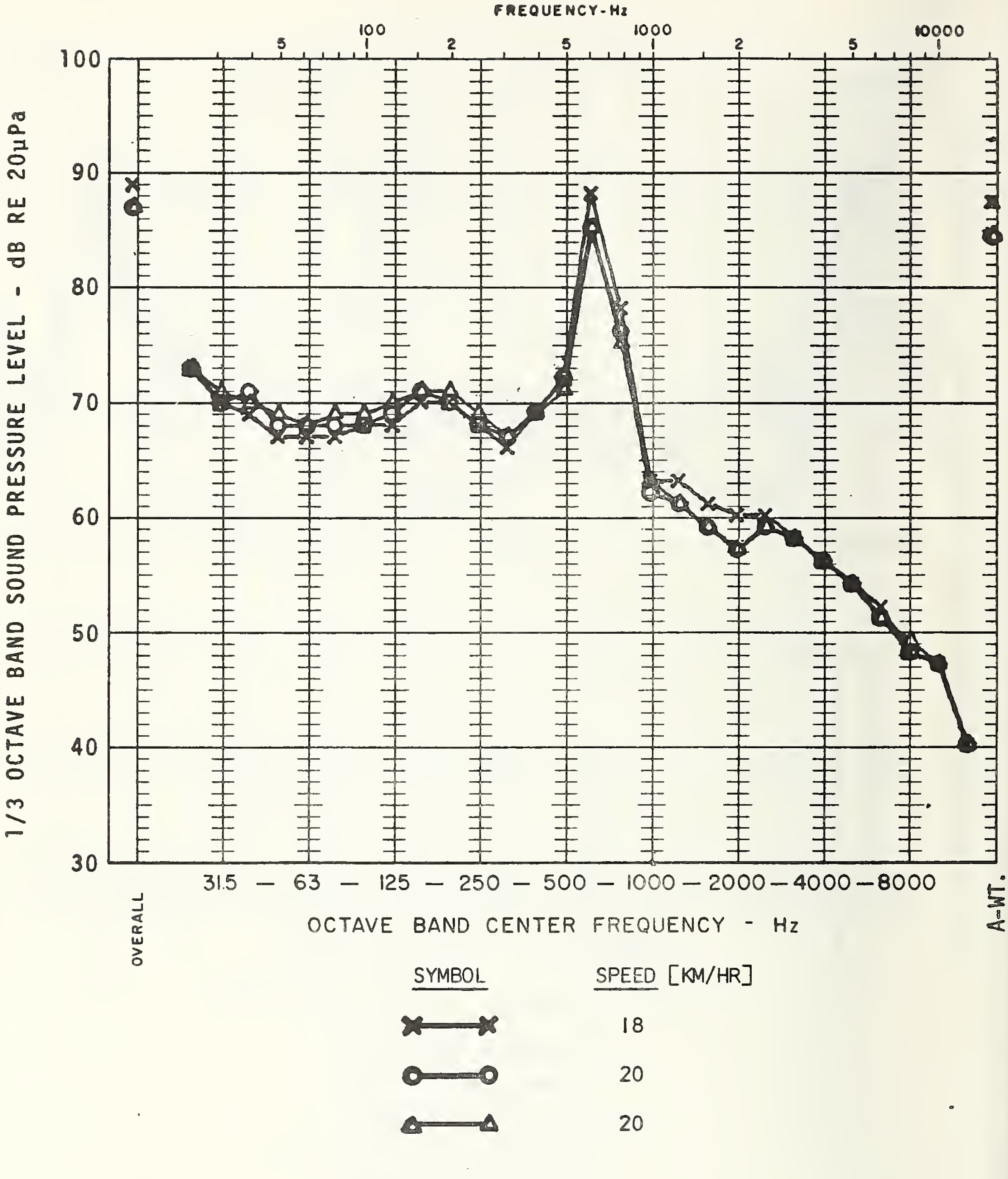


FIGURE D-5. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IIA; OCTOBER 3, 1976
CONTROL TRACK, WAYSIDE - TRUED STANDARD WHEELS
WET TRACK

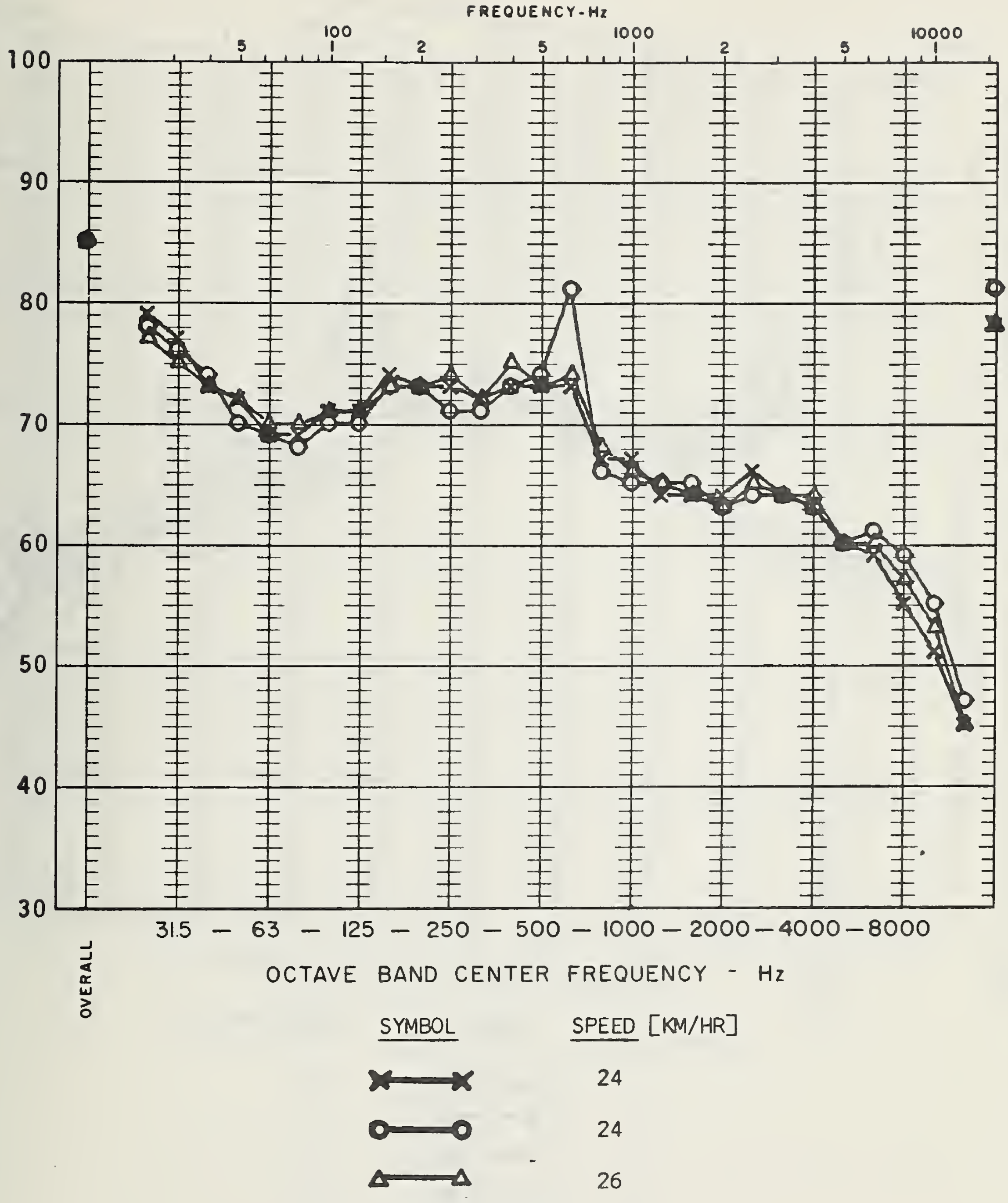


FIGURE D-6. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IIA; OCTOBER 3, 1976
TEST TRACK, WAYSIDE - TRUED STANDARD WHEELS
WET TRACK

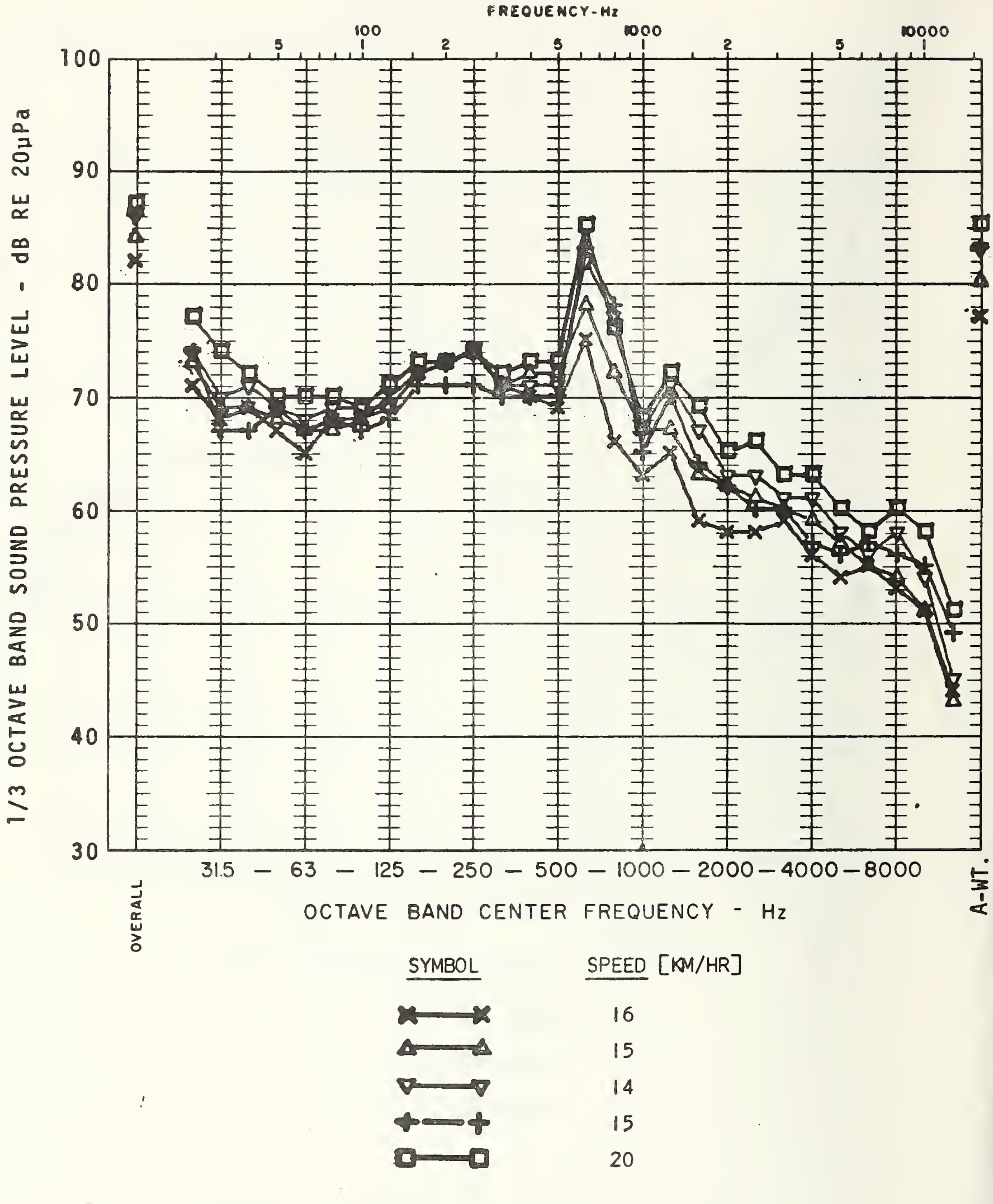


FIGURE D-7. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IIA; OCTOBER 3, 1976
CONTROL TRACK, WAYSIDE - NEW RESILIENT ACOUSTAFLEX WHEELS

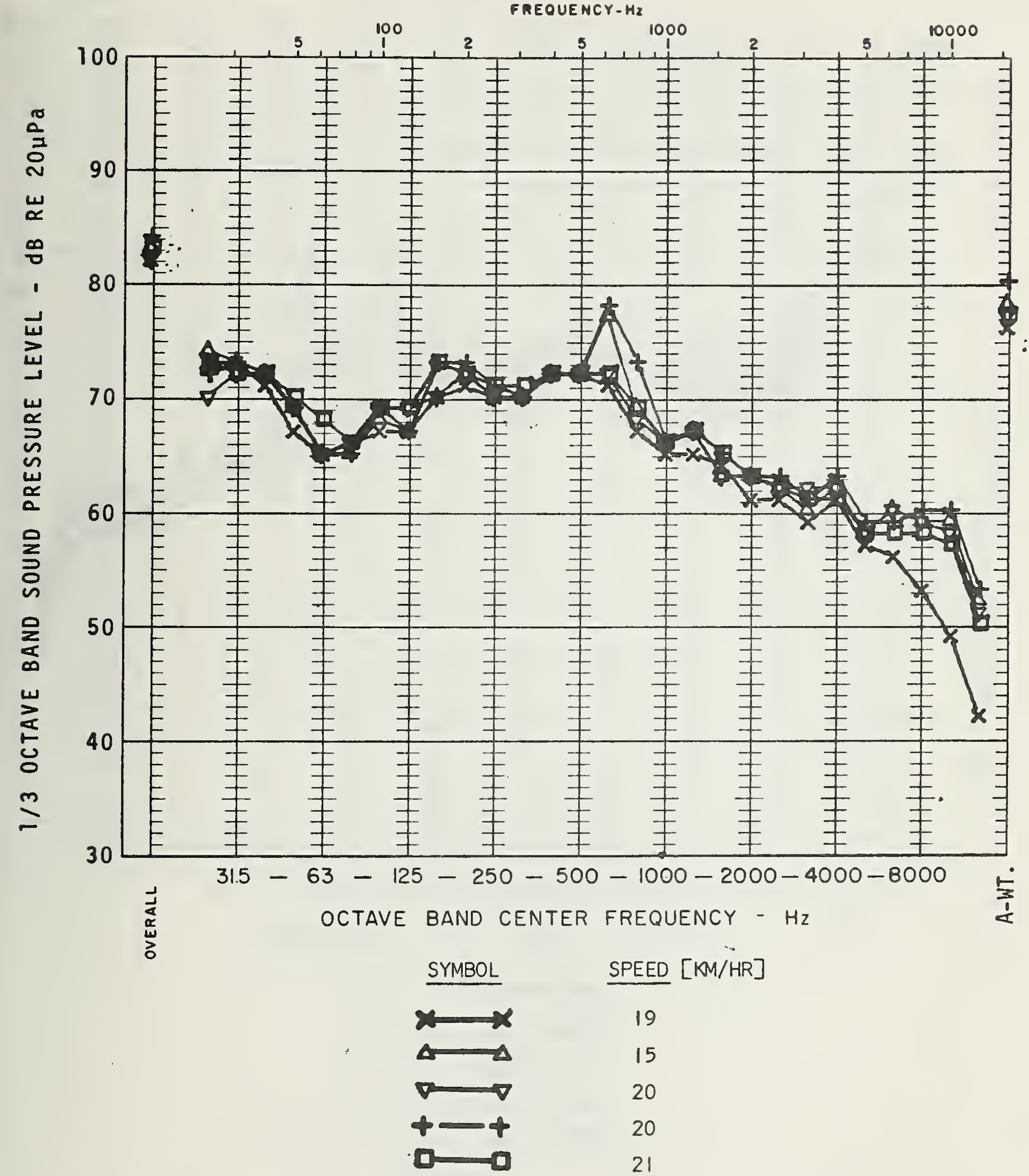


FIGURE D-8. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IIA; OCTOBER 3, 1976
TEST TRACK, WAYSIDE - NEW RESILIENT ACOUSTAFLEX WHEELS

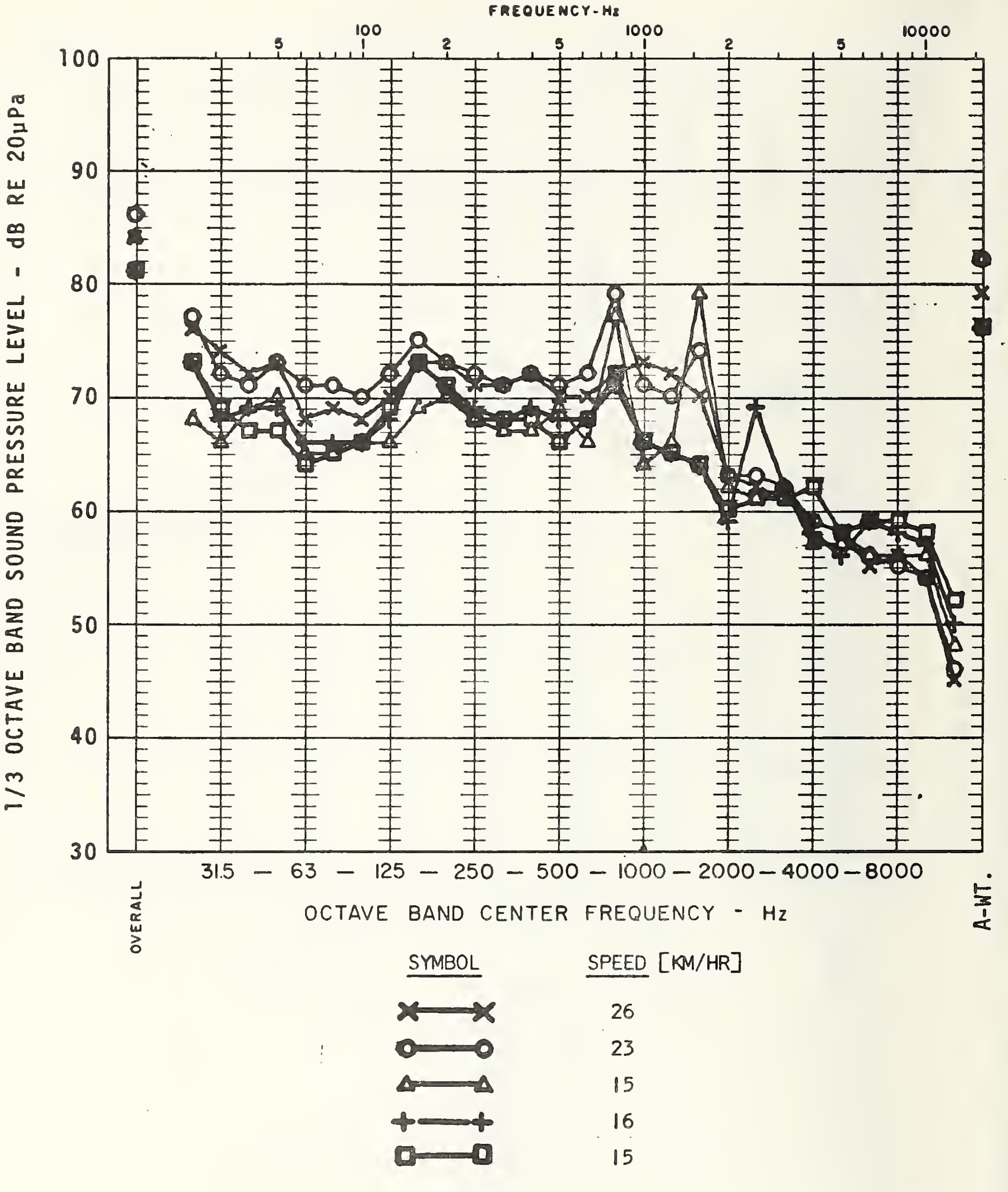


FIGURE D-9. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IIA; OCTOBER 3, 1976
CONTROL TRACK, WAYSIDE - NEW PENN BOCHUM RESILIENT WHEELS

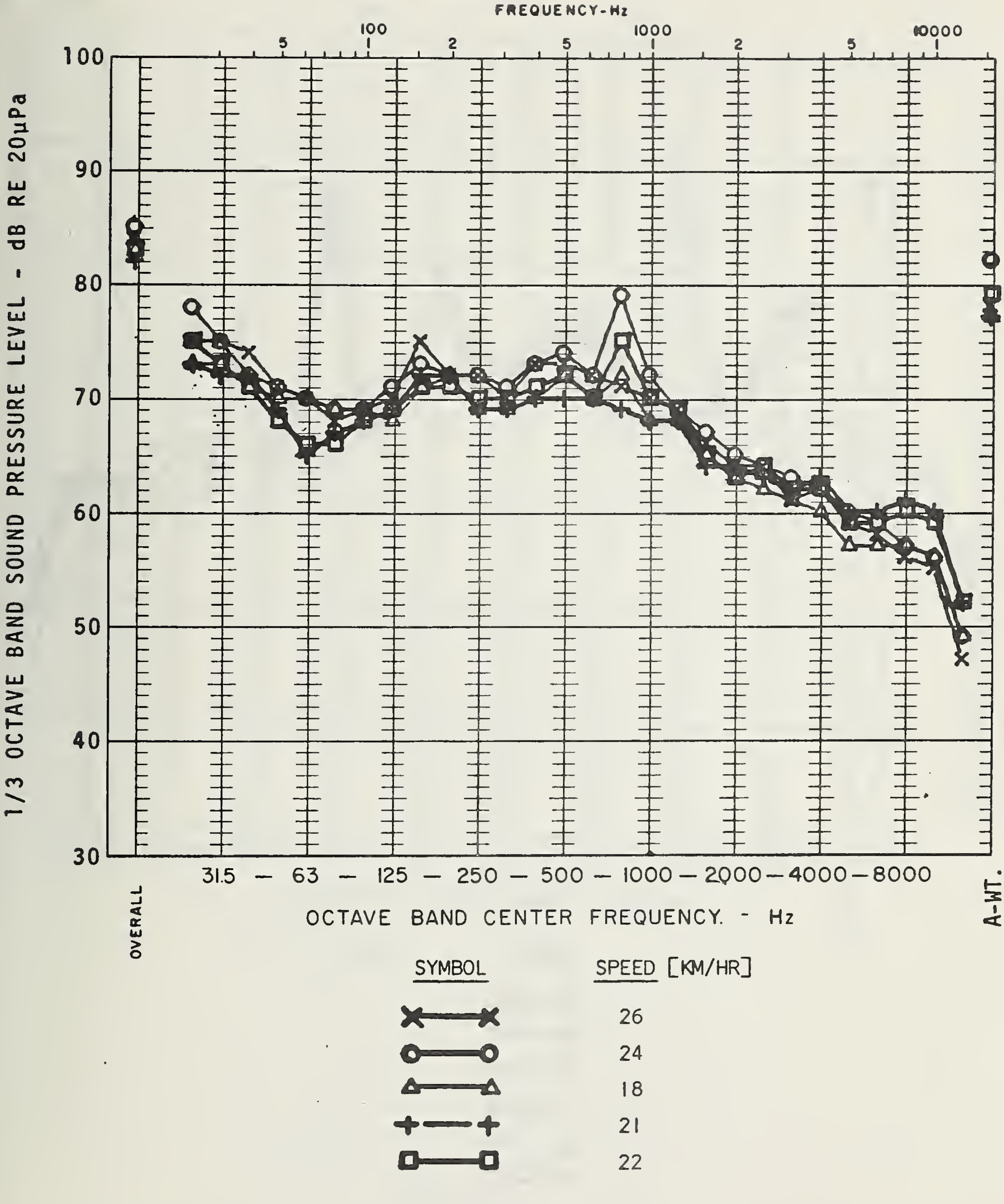


FIGURE D-10. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IIA; OCTOBER 3, 1976
TEST TRACK, WAYSIDE - NEW PENN BOCHUM RESILIENT WHEELS

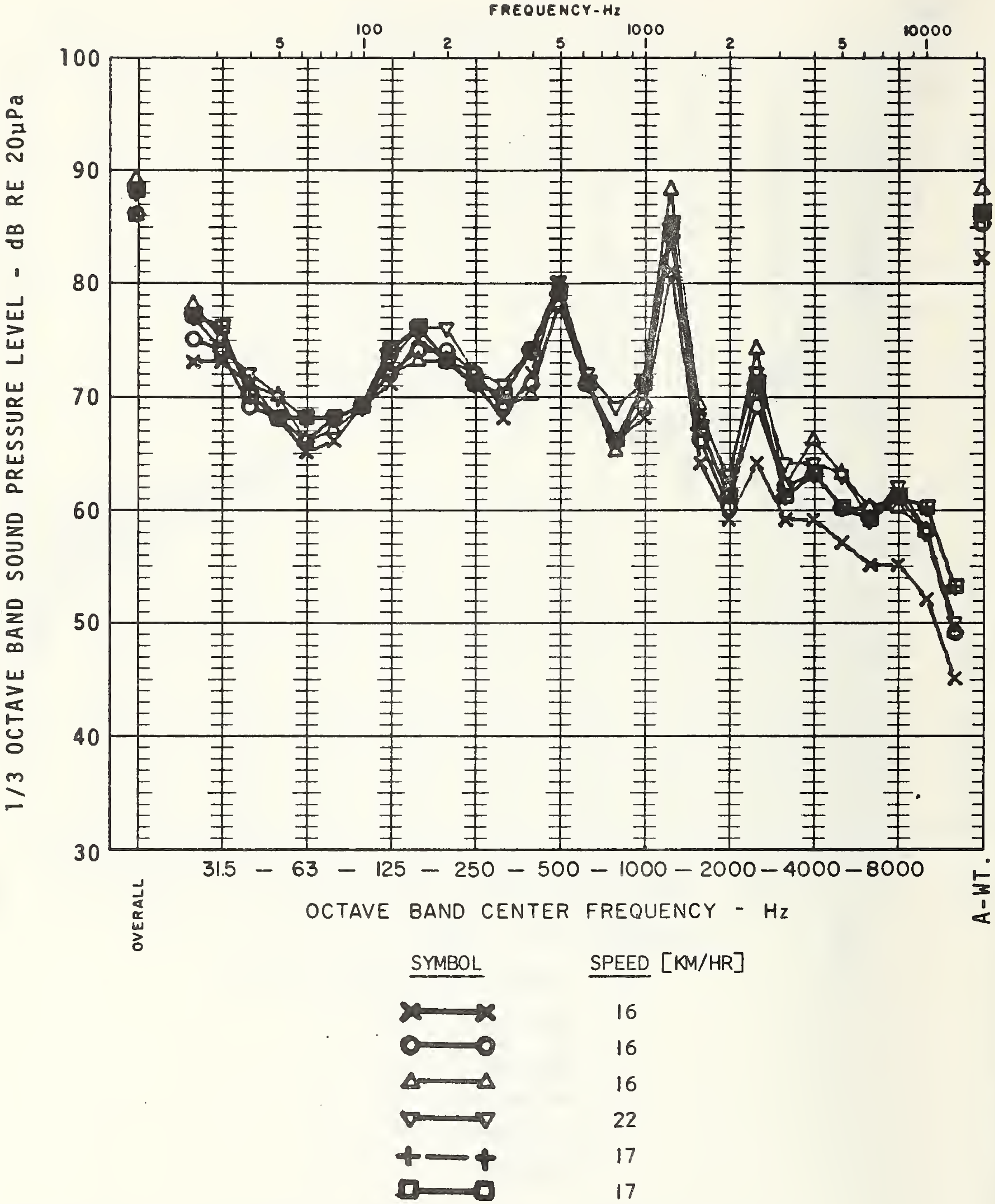


FIGURE D-11. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IIA; OCTOBER 3, 1976
CONTROL TRACK, WAYSIDE - NEW SAB RESILIENT WHEELS

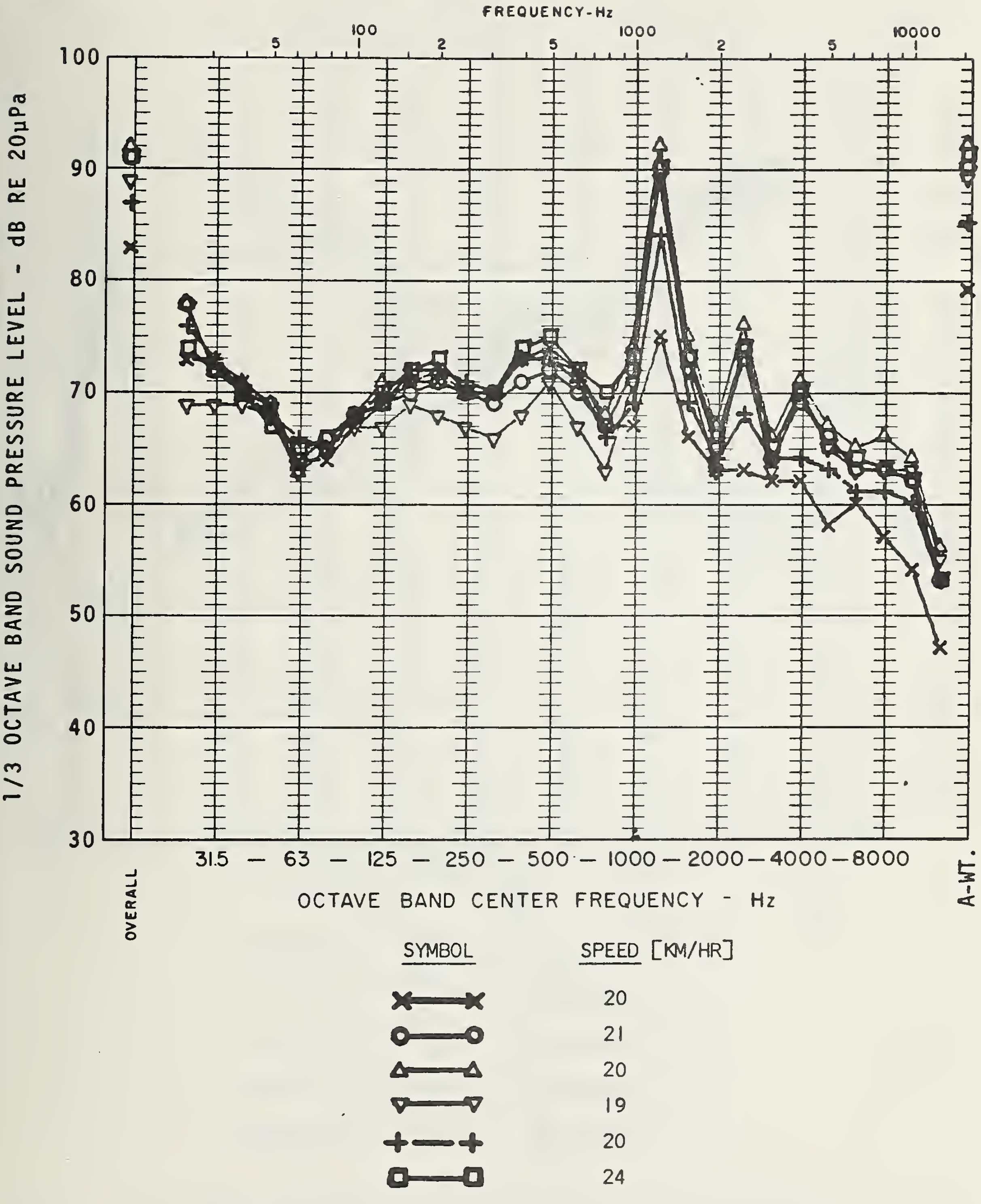


FIGURE D-12. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IIA; OCTOBER 3, 1976
TEST TRACK, WAYSIDE - NEW SAB RESILIENT WHEELS

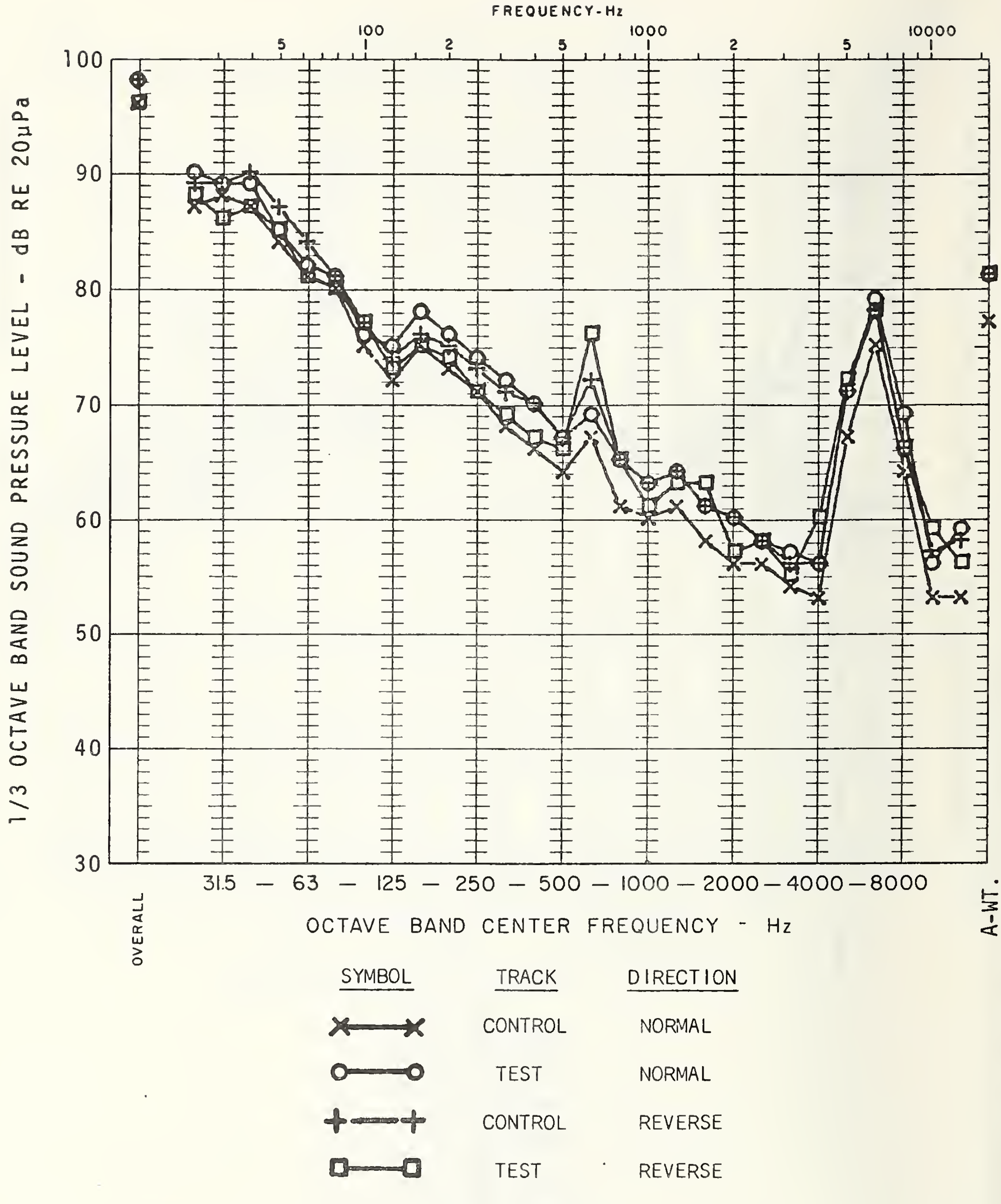


FIGURE D-13. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IA; JULY 15, 1976 - ENERGY AVERAGE OF ALL SAMPLES
CAR INTERIOR, OVER TRUCK - WORN STANDARD WHEELS

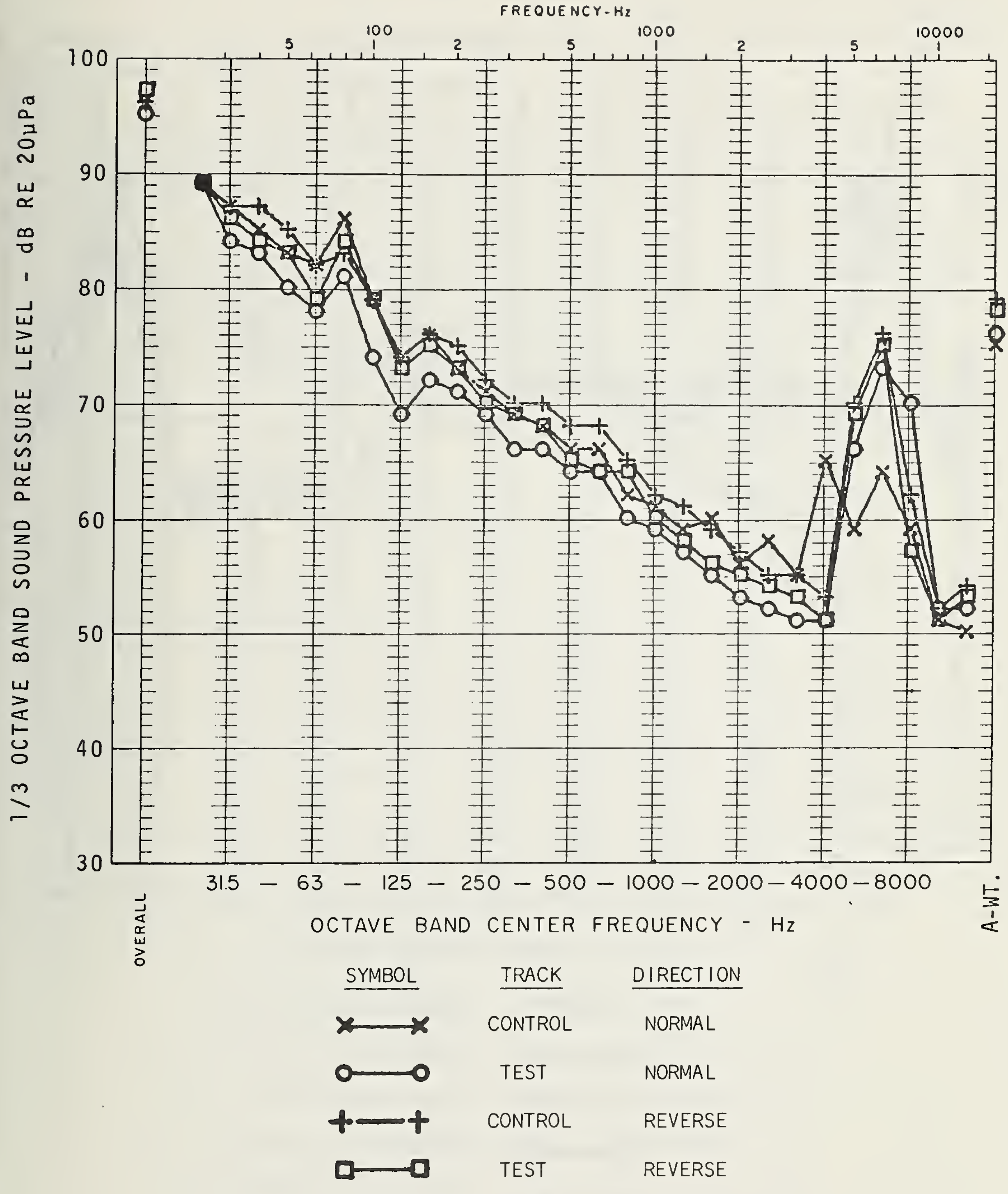


FIGURE D-14. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IA; JULY 15, 1976 - ENERGY AVERAGE OF ALL SAMPLES
CAR INTERIOR, OVER TRUCK - NEW STANDARD WHEELS

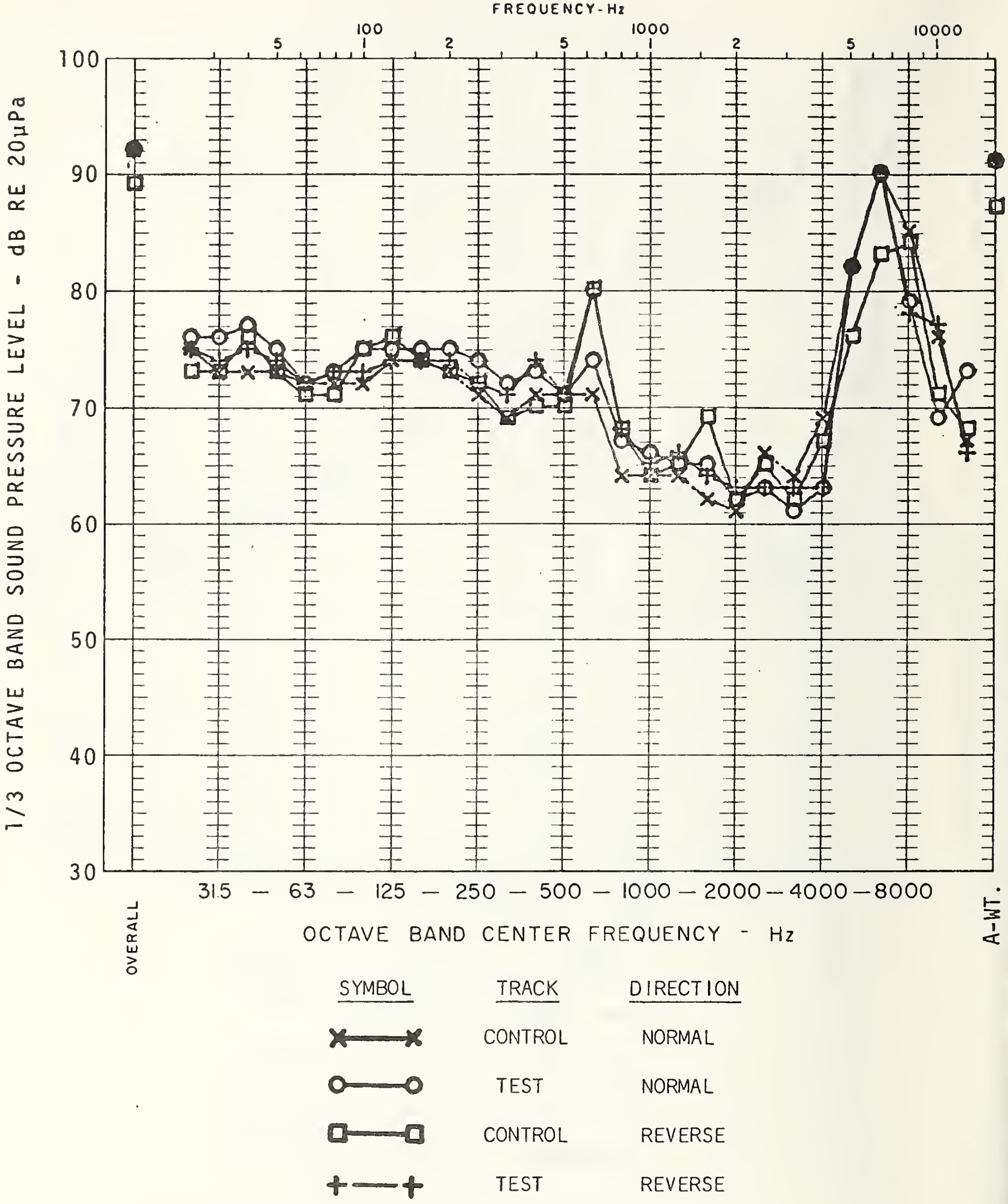


FIGURE D-15. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IA; JULY 15, 1976 - ENERGY AVERAGE OF ALL SAMPLES
WAYSIDE - WORN STANDARD WHEELS

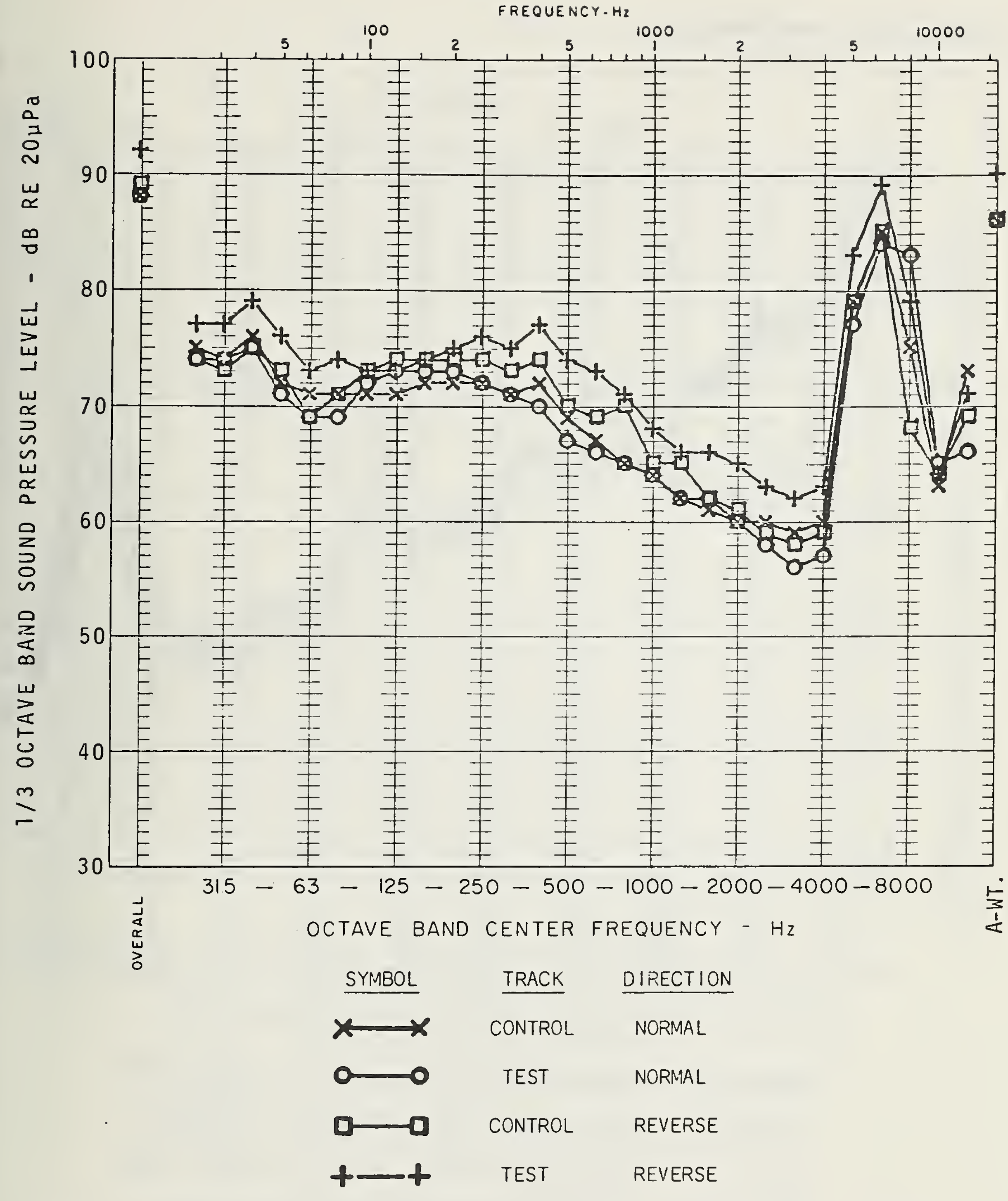


FIGURE D-16. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IA; JULY 15, 1976 - ENERGY AVERAGE OF ALL SAMPLES
WAYSIDE - NEW STANDARD WHEELS

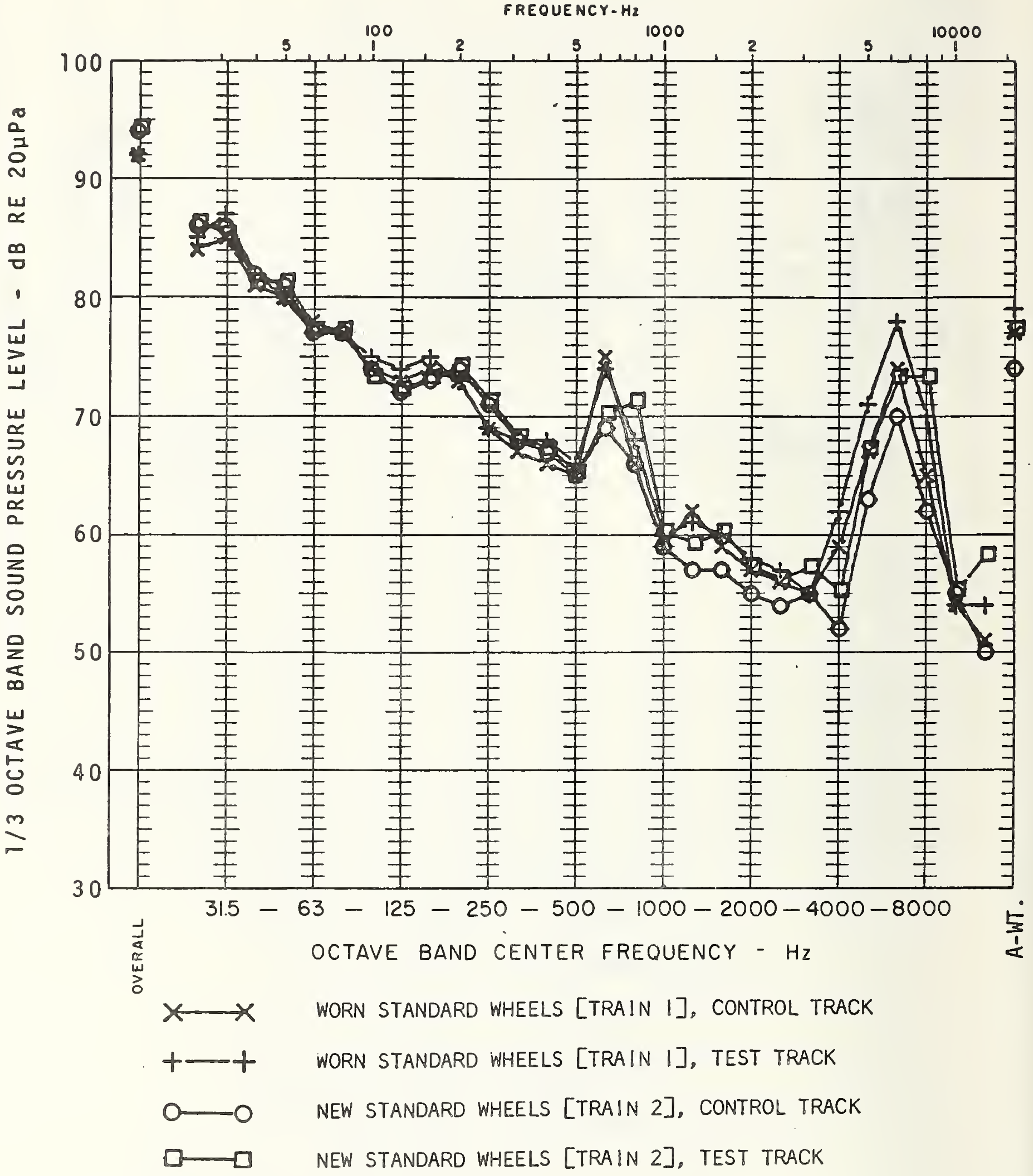


FIGURE D-17. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IB; AUGUST 18, 1976
AVERAGE OF ALL SAMPLES [ENERGY] AND BOTH CHANNELS [LINEAR]
CAR INTERIOR

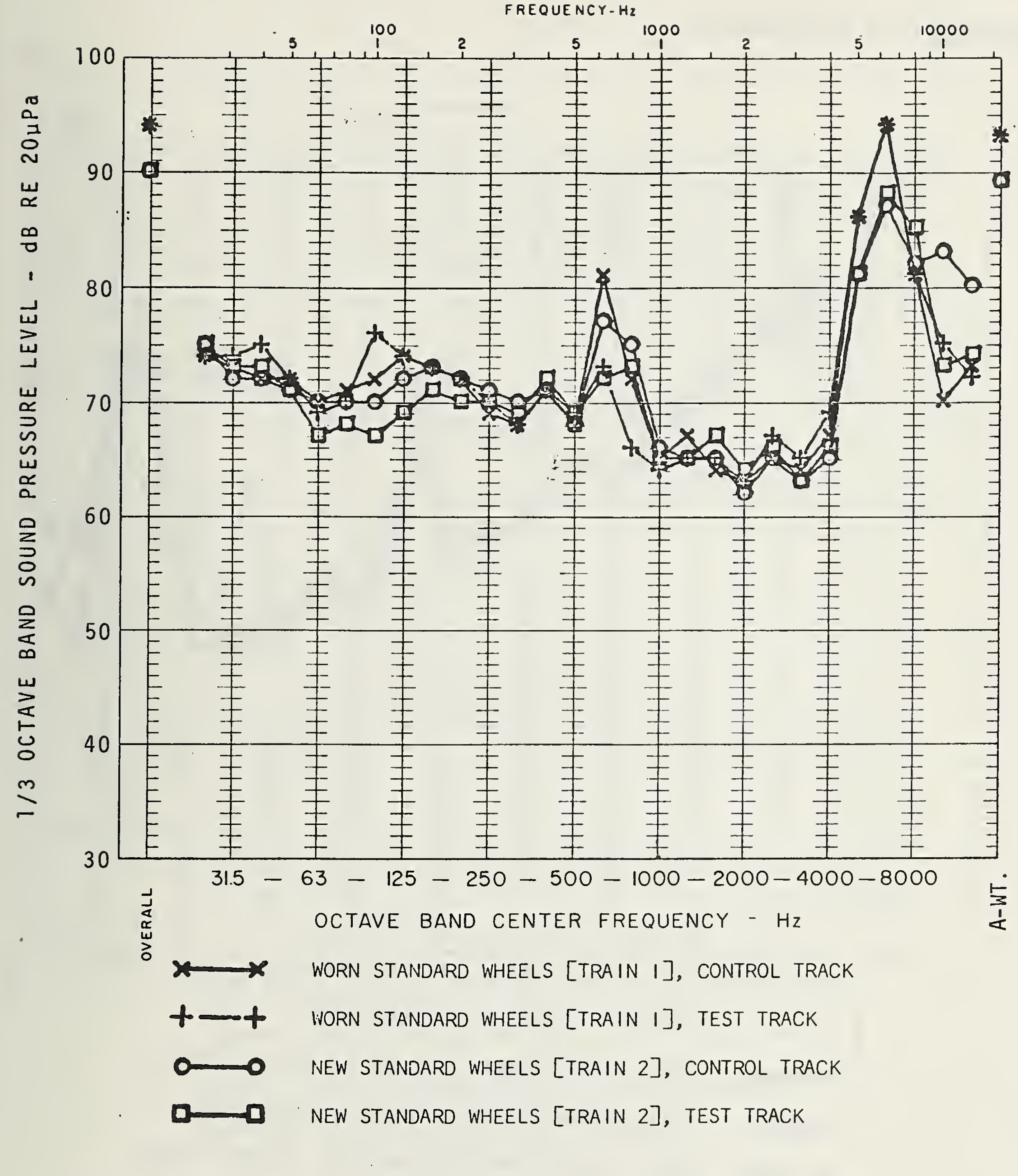


FIGURE D-18. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IB - AUGUST 18, 1976
ENERGY AVERAGE OF ALL SAMPLES
WAYSIDE

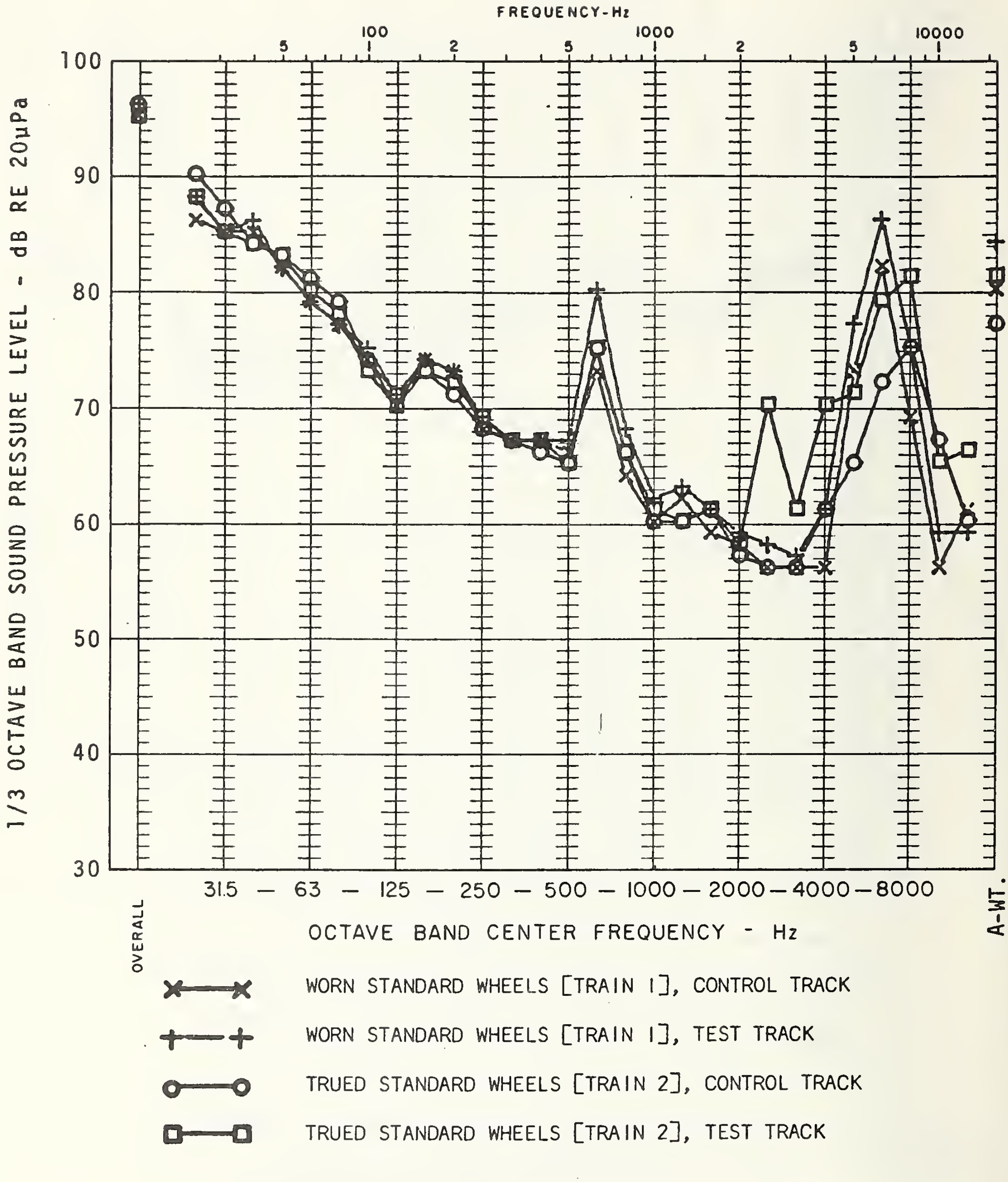


FIGURE D-19. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IC; SEPTEMBER 1, 1976
AVERAGE OF ALL SAMPLES [ENERGY] AND BOTH CHANNELS [LINEAR]
CAR INTERIOR

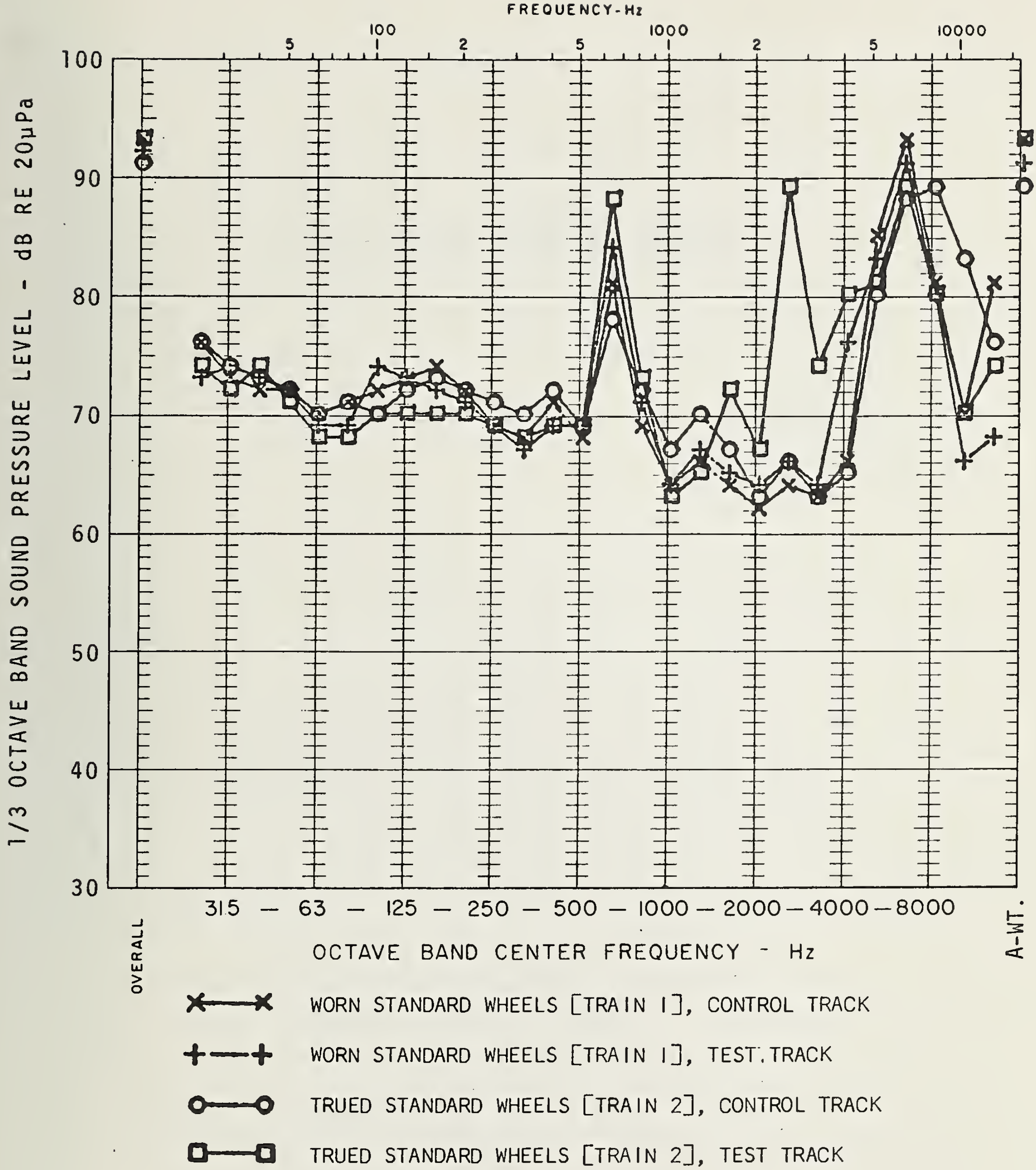


FIGURE D-20. SHORT RADIUS CURVE AT 69TH STREET TURNAROUND
PHASE IC; SEPTEMBER 1, 1976
ENERGY AVERAGE OF ALL SAMPLES
WAYSIDE

APPENDIX E

SURVEY OF RAPID TRANSIT SYSTEMS

E.1 CHICAGO TRANSIT AUTHORITY

System Description

The Chicago Transit Authority (CTA) was formed in 1948, combining the services of the Chicago Surface Lines and Chicago Rapid Transit Company. After absorbing the Chicago Motor Coach system, it now operates all rail and bus transit systems in Chicago and surrounding Cook County. CTA operates approximately 1,200 rail revenue vehicles, (see Table E-1) an annual average of 45,000 miles each.

CTA operates on 191.6 miles of revenue track including: 20.3 miles of subway track, all welded rail, predominantly on wood ties in concrete and a lesser amount of wood ties and ballast; 89.2 miles of surface track, 63 miles of which is welded, on concrete ties and ballast; 82.1 miles of elevated track, all of which is jointed, on wood tie-open deck structure. The track gauge is 4 feet, 8½ inches.

The minimum radius curves, 90 feet, occur in the downtown elevated sections. Rail lubrication has been utilized on these and other curves for forty years. This lubrication, originally employed to reduce wear, has a marked but erratic noise reduction effect. Rail lubrication has doubled curve rail life to 10-15 years.

Ring Damped Wheels

In 1975, CTA installed sixteen ring damped wheels on two 2000 series revenue cars. CTA modified standard solid steel wheels to a ring damped configuration in house in accordance with drawings provided by Boeing Vertol. After one year of service, no problems in operation, maintenance, or inspection were experienced.

In the fall of 1976, two-car sets of aluminum-centered ring-damped wheels were tested. Again, no difficulties were experienced.

Acoustical data taken by Boeing Vertol indicated a 1-2 dBA reduction on level tangent track and as much as 15-20 dB reduction in the squeal frequency on curved track with either type of ring damped wheels.

Eight CTA revenue vehicles are presently operating with ring-damped wheels, and additional conversions are planned. CTA is installing damping rings in the wheels of all 200 new Boeing-Vertol cars.

Rail Grinding

Prior to 1972, rail grinding at CTA was accomplished with a small Lowe grinder cart. This cart, equipped with three abrasive bricks over each rail, was pulled or pushed by a motorized car. It was repeatedly run over short single-tracked sections during night hours.

In 1973, CTA converted a passenger car into a rail grinder car. The motor was removed from one truck and replaced by an abrasive brick carriage over each rail. The CTA designed brick carriages, containing seven bricks each, are raised and lowered by an 80 psi pneumatic system operated from within the car. Additionally, a 5,000-gallon weed killer tank car was converted into a water car, to spray ahead and behind the grinder truck. This water spray is utilized only on elevated track to minimize fires on the pine ties and decking. Three 4000 series motor cars were used to pull the grinder and water cars during revenue service.

In 1977, the second grinder car truck was replaced with a grinding carriage truck. The 4000 series motor cars were also

replaced with four 6000 series motor cars. These 6000 series cars are permanently coupled in pairs, incorporate automatic train controls, and are interchangeable with other revenue service vehicles.

Table E-2 lists CTA rail grinder equipment.

The grinder train travels at an average speed of 20 mph during the six daylight hours between peak traffic and at an average 40 mph at night. No grinding is performed during peak hours. All grinding is performed between revenue service trains without affecting revenue schedules or creating out-of-service track. Once the grinder train is on the track section to be ground, no switching is necessary and no reverse running is permitted.

Based on 1975 data, employing the single grinder truck car, 80 miles of track were ground annually with an average of 225 passes per mile of track. It is anticipated that the addition of the second grinder truck will result in 160 miles being ground per year, at 112 passes per mile, while the train travels the same 18,000 miles per year.

Table E-3 lists CTA rail grinding operational personnel and their hourly wage. Typically, one hour is consumed changing/adjusting bricks (.75 hr.) and hooking up the four 6000 series cars (.25 hr.) each day the grinder is operated. Additionally, travel to and from grinder berthing and working areas consume approximately one half hour daily. Every few weeks, 1½ hours are consumed in transit between various CTA lines when grinding operations are shifted.

The primary objective of CTA's rail grinding program is noise reduction. The apparent reduction in equipment vibration and probable enhancement of equipment life has not been evaluated. With the two grinding truck cars, CTA has targeted

a one and a half year grinding cycle for the entire system. CTA suspects that its optimum grinding schedule would be somewhat more frequently than an annual cycle.

All revenue track is included in the grinding program. Storage and yard track is not included. Rail corrugation and noise levels are not routinely measured as part of the grinding program. However, measurements made in early 1976 indicate:

a. The most severe rail corrugation develops outbound from station berthing areas to 200 feet beyond the platform. Corrugation in these areas is approximating 0.01 inches in depth.
b. Between station areas rail corrugation averages 0.005 inches.
c. Rail corrugation does not exist in braking areas 200 feet before and into station areas. Rail wear in these areas, however, requires rail replacement twice as frequently as the systems 40-year average.

CTA noise measurements made before and after grinding on both open deck elevated track and subway track indicate that reductions of as much as 10 dBA are possible as a result of eliminating rail corrugations by grinding. Typically, rail grinding at CTA is attributed with 3-6 dBA noise reductions.

Categorically, CTA reports train noise levels to be highest on curves, less severe when accelerating, and least pronounced during normal running and braking. During braking the noise contribution of dynamic braking is probably significant. Ballasted track, especially with wood ties, definitely results in less noise than non-ballasted and concrete tie sections.

Table E-3A lists the annual rail grinder costs at CTA. Since annual maintenance costs are not available, the overall

cost of the grinding program is not specified. Only operating and inspection costs are quantified.

Wheel Truing

CTA has trued wheels since the inception of service. Axle sets of two wheels are reprofiled on an above floor lathe and wheel grinder. All wheel truing is accomplished at the Skokie Shop. An average 830 axle sets are trued per year. Wheels are inspected visually and with AAR wheel gauges at 6,000-mile intervals. Wheel life averages one million miles before condemnation at 0.75 inch tire thickness on both 26 and 28-inch wheels. New tire thickness is two inches. The average wheel is turned every 300,000 to 400,000 miles.

Typically, axle sets of two wheels are removed from the car at one of five terminal shops and transported by highway vehicle to the Skokie Shop for truing. The entire truck is removed only if the truck itself requires overhaul or repair. CTA criteria requires wheels to be trued to within 0.05 inches measured on the diameter, grinding to a 125 micro inch finish and wheels on the same axle to be within 0.05 inches. Actual truing time varies with the size of the wheel. Truing takes approximately 1.5 hours for 26-inch wheels and 2.5 hours for 28-inch wheels.

Table E-4 lists the categories and hourly wages of personnel involved in wheel truing and wheel changing at CTA. Table E-5 lists the average manpower expenditures associated with wheel truing time based on the total number of 26 and 28-inch wheels in the CTA revenue vehicle fleet. Table E-6 lists the procedures and expenditures associated with wheel changing at CTA. Table E-7 lists the annual wheel truing consumable component expenditures at CTA. Table E-8 lists the CTA equipment associated with wheel truing and changing.

CTA is currently in the process of obtaining an underfloor wheel lathe to be installed at the main shop. This will facilitate wheel truing and hopefully reduce the time and cost.

TABLES E-1. CTA REVENUE VEHICLES

MANUFACTURER	SERIES	UNLOADED WEIGHT (LBS)	TRUCK TYPE	WHEEL TYPE	CAR PURCHASE DATE/COST	NUMBER OF CARS
St. Louis	4	50,900	LFM-CTA #1	28" Steel	1958/$ 60,000@	1
St. Louis	5-50	46,500	St. Louis B-3	26" Steel	1958/$ 54,800@	46
Pullman	51, 75*	94,300	Clark Special	28" Steel	1947/$ -	2
St. Louis	53-54	92,700	St. Louis B-4	28" Alum.	1948/$ -	2
St. Louis	6001-6200**	42,000	Clark B-2	26" Steel	1950/$ 38,500	194
St. Louis	6201-6470**	43.200	Clark B-2	26" Steel	1953/$ 33,140@	262
St. Louis	6471-6510**	41,750	Clark B-2	26" Steel	1955/$ 40,650@	40
St. Louis	6511-6550**	44,350	St. Louis B-3	26" Steel	1955/$ 40,650@	40
St. Louis	6551-6670**	44,350	St. Louis B-3	26" Steel	1956/$ 44,250@	120
St. Louis	6671-6720**	44,350	St. Louis B-3	26" Steel	1958/$ 49,560@	49
St. Louis	6721-6722**	42,700	Clark B-2	26" Steel	Formerly 6454 & 6310	2
Pullman	2001-2180**	47,300	LFM-CTA #1	28" Steel	1964/$106,000	178
Budd	2201-2350**	45,000	Pioneer III	28" Alum.	1969/$126,000	150
Boeing Vertol	2401-2600**	50,500	Wegmann	28" Alum.	1976/$300,000	90[b]
					Total:	1,176

* Three compartment cars

** Permanently coupled in pairs

@ Converted from PCC street cars

b will have 200 cars by 1/1/79

Notes: (A) 2000 and 2200 series cars have self-ventilated motors with internal fans; all other series cars have forced ventilated motors with external fans.

(B) Brakes: 2000 and 2200 series cars - rated dynamic braking to 4-5 mph, then disc brakes; 2400 series cars - rated dynamic braking to 3 mph, then disc brakes; all other series cars - rated dynamic braking to 1 mph, then drum brakes.

TABLE E-2. CTA RAIL GRINDER EQUIPMENT

MANUFACTURER	SERIES	PROCUREMENT DATE/COST	FUNCTION	REMARKS
Cincinnati Car	4358	1972/$18,000*	Abrasive brick rail grinder	Converted in-stock passenger car
Standard	1501	**	Water tank/ pump car	Converted tank car
St. Louis	6000	1950/$38,500	Pull grinder train	4 in-service revenue cars
-	(servicing pit)	-	Provide safe access to change bricks	Various throughout system

* Approximate cost of converting motor truck into grinding truck with pneumatically controlled brick carrier. In 1977, second truck converted to grinding truck.

** Originally 40-ton flat car, converted into weed killer tank car, again refurbished into water car in 1972. In system since 1938.

TABLE E-3. CTA RAIL GRINDER PERSONNEL

EMPLOYEE	HOURLY/ WITH WAGE/BENEFITS	TASK
SWITCHMAN	$8.11/$11.35	Operates track switches
MOTORMAN	8.04/ 11.26	Operates train
TRACKMAN	8.03/ 11.26	Two-men classified as Loader Grinder Operator; change and adjust bricks, operate brick pneumatics and water car.
CONDUCTOR	7.93/ 11.10	Oversees operation of train

Note: Switchman, motorman, and conductor rotated through similar grinder train and revenue train tasks.

Wages and benefits reflect 1977 dollars.

TABLE E-3A. CTA RAIL GRINDING COSTS

OPERATION		
PERSONNEL	ANNUAL COST*	REMARKS
Switchman Motorman 2-Trackmen Conductor	$ 18,126 17,982 35,964 17,727	Based on rates contained in Table E-3 and 1597 operating hours per year
CONSUMABLES		
Abrasive bricks Water	$ 12,000 Unavailable	1714 used at $7 each Approximately 250,000 gallons used
Annual Operating Sub-Total	$101,799	Based on 80 miles ground in 1597 operating hours (approximately 200 eight-hour shifts)
MAINTENANCE		
INSPECTION	$ 1,696	2 inspectors, 8 hours each, every 2 weeks plus annual 90 man-hour inspection (does not include 6000 series motor cars)
REPAIR/UPKEEP	Unavailable	No data available on personnel or material costs for repairs
ANNUAL TOTAL COSTS	-	Incomplete maintenance cost data

*1977 dollars

TABLE E-4. CTA PERSONNEL WHEEL TRUING/CHANGING

EMPLOYEE	HOURLY/ WITH WAGE/BENEFITS	TASKS	PERCENT OF TIME ASSIGNED TASKS
MACHINIST	$9.03/$12.64	Operate lathe & grinder, sharpen tools	100
ELECTRICIAN	8.90/ 12.46	Disconnect electric leads when removing truck	-
SHOPMAN	8.90/ 12.46	Assist in operating lathe & grinder, sharpen tools	100
SHOPMAN I	8.90/ 12.46	Remove axle, steam clean axle	-
CHAUFFEUR	8.40/ 11.75	Drive highway truck transferring axle sets between terminal shop and Skokie Shop	-
REPAIRMAN	8.30/ 11.62	Only at terminal shops: disconnects trucks, removes axles, operates forklift	-
TRACTOR OPERATOR	7.92/ 11.09	Operates forklift at Skokie Shop, transports axle sets within shop	-

Note: Wages and benefits reflect 1977 dollars.

TABLE E-5. CTA WHEEL TRUING PROCEDURE

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (E)	Remarks
1.	REMOVE AXLE	1	2 repairmen	1	2	$ 23.24	Includes handling
2.	CLEAN AXLE	.25	1 shopman I	.25	.25	3.12	Steam clean
3.	TRUE WHEELS (axle set of 2 wheels)	1.8	1 machinist 1 shopman	1.8 1.8	1.8 1.8	22.75 22.43	Average weighted time for 26" and 28" wheels
4.	INSTALL AXLE	2.5	2 repairmen	2.5	5	58.10	Includes handling, realignment, etc.
5.	TRANSPORT AXLE						
	a. within shop	.4	1 tractor operator	.4	.4	4.44	By forklift
	b. outside shop	.75	1 chauffeur	.75	.75	8.82	By highway vehicle
	Total	6.7			12.0	142.90	

NOTES:

A. Unless wheels are being trued in conjunction with truck overhaul, it is not necessary to remove truck.

B. Step 5.b., transporting of axle outside shop, between terminal shop and Skokie shop, same cost for one axle set or one car set of four axles.

C. Average total truing and handling time/labor costs prorated for one axle set of two wheels: ELAPSED TIME = 6.7 hours; MAN HOURS = 12; LABOR COST = $142.90.

D. Average total truing and handling time/labor costs prorated for one car set of eight wheels: ELAPSED TIME = 24.55 hours; MAN HOURS = 45.75 ; LABOR COST = $545.14.

E. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-6. CTA WHEEL CHANGING

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (D)	Remarks
1.	REMOVE AXLE	1	2 repairmen	1.0	2.0	$ 23.24	Includes handling
2.	CLEAN AXLE	.25	1 shopman I	.25	.25	3.12	Steam clean
3.	PRESS OFF WHEELS	.67	1 machinist	.67	.67	8.47	Includes handling
	(axle set of 2 wheels)		1 shopman	.67	.67	8.35	
4.	BORE 2 WHEELS	5.0	1 machinist	5.0	5.0	63.20	Includes handling
5.	PRESS ON WHEELS	.67	see remarks		1.34	16.82	Reverse of PRESS OFF WHEEL above
6.	INSTALL AXLE	2.5	2 repairmen	2.5	5.0	58.10	Includes handling
7.	TRANSPORT AXLE						
	a. within shop	.5	1 tractor operator	.5	.5	5.55	By forklift
	b. outside shop	.75	1 chauffeur	.75	.75	8.82	By highway vehicle
	Total	11.34			16.58	$195.67	For one axle set

NOTES:

A. Unless wheels are removed in conjunction with truck overhaul, it is not necessary to remove truck.

B. Step 7.b., transporting axle outside shop, between terminal shop and Skokie shop, same cost for one axle set or one car set of four axles.

C. Average total wheel changing time/labor costs prorated for one car:
ELAPSED TIME = 46.11 hours; MAN HOURS = 62.47; LABOR COST = $756.22.

D. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-7. CTA WHEEL TRUING ANNUAL CONSUMMABLE MATERIAL

Description	Annual Cost (each)	Usage/Cost	Remarks
LATHE TOOLS:			
Chamfering tool	$ 57.50	10/$ 575	approx. 200 hr/tool
Roughing tool	93.00	56/$5,200	approx. 71.5 hr/tool
Flange finishing tool	73.50	6/$ 441	approx. 666 hr/tool
Cylinder roughing tool	19.50	12/$ 234	approx. 166.5 hr/tool
SUBTOTAL		$6,450	
GRINDER:			
Grinding wheels	$190	18/$3,420	approx. 222 hr/replacement
TOTAL		$9,970	for approximately 830 axle sets

NOTE: No data on electric power, water, steam, or lubricant consumption. Costs reflect 1977 dollars.

TABLE E-8. CTA WHEEL TRUING/CHANGING EQUIPMENT

Manufacturer	Series/Type	Procurement Date/Cost	Function	Remarks
Wm. Sellers & Co.	Model: 1439	-/$-	above floor wheel lathe	No trace control
American Car & Foundry Co.	Model: ACFFG31 No. 280529	-/$-	wheel grinder	Water spray supply and drainage
Niles	(400 ton)	-/$-	wheel press	-
Betts, Newton, Colburn	Ser. #E7443	1927/$-	wheel bore	-
Enerpac	Model: PEM2021 Ser. #OL5122	-/$-	hydraulic assist for pressing off aluminum centered wheels	motor driven (lhp); 190 cubic inch capacity; up to 10,000 psi
Various	(5-ton forklift)	-/$-	transport axle sets within shop	also transfer axle sets to/from highway vehicle
-	(Steam cleaning room)	-/$-	clean axle set before turning wheels	-
Various	(screw jacks)	-/$-	lift car body to remove axle/truck	at various terminal shops

E.2 GREATER CLEVELAND REGIONAL TRANSIT AUTHORITY

System Description

In 1975, the operation of the Cleveland Transit System, the Shaker Heights line, and various suburban Cleveland bus lines were combined under the Greater Cleveland Regional Transit Authority (GCRTA). The heavy rail transit system operated by GCRTA has been in service since 1955. It operates 117 revenue vehicles, listed in Table E-9. The Pullman cars operate an average of 75,000 miles per year; the St. Louis cars average 20,000 miles per year.

All but one mile of the 39 miles of revenue track is on the surface. The one mile of subsurface track services the Public Square and Airport stations. An overhead wire power distribution system is used throughout. All tracks consist of 100-pound ARA-A rail on wood ties and ballast. Twelve miles of this track are shared with GCRTA's light rail system. The track gauge is 4 feet, 8 inches.

Automatic pressurized rail lubricators are employed on selected curves to minimize noise, especially near residential areas. The 90-foot radius curve yard track at Windermere Loop is the tightest curve in the system. The smallest radius curve in the main line is 300 feet.

Resilient Wheels

In 1975, two SOAC vehicles equipped with Acousta Flex wheels were run on the GCRTA heavy rail line for three weeks. During that time the wheels experienced two problems. First, the rim rotated with respect to the hub due to a bonding failure.

Second, due to improper fitting of the wheel to the axle, several wheels began to come off. No other resilient wheels have been used on the heavy rail system.

Conventional P.C.C. resilient wheels have been utilized on the GCRTA light rail system since 1948. This 57-car system utilizes dynamic braking to three miles per hour, then applies drum friction brakes and track brakes.

Rail Grinding

Rail grinding is not incorporated in GCRTA's rail maintenance program. The system was last ground in 1966. The rail grinding was contracted, and all grinding was done at night. Though the light rail system experiences significant corrugation along long, sweeping curves and in station departure areas, there is reportedly no significant corrugation or rail irregularities on the heavy rail system which will warrant rail grinding in the near future.

Wheel Truing

For the first four years of revenue service, GCRTA maintained heavy rail system wheels with a wheel grinder at the Windermere Shop. In 1959, an above-floor wheel lathe was installed at Windermere Shop to maintain wheels. In January 1976, an under-floor wheel lathe was installed at the new Brook Park Service and Inspection Shop. Since this time, the 28-inch solid steel heavy rail system wheels and the 26-inch light rail system P.C.C. resilient wheels have been trued at Brook Park.

Heavy rail system wheel life varies with the type of car at GCRTA. The Pullman car wheels average 200,000 to 250,000 miles. The St. Louis car wheels average 450,000 to 500,000 miles. The same 28-inch solid steel wheels are used on both cars. They are condemned at a 26-inch diameter and trued after approximately 75,000 miles. Wheels are required to be concentric within 0.010 inch and wheel run-out shall not exceed 0.010 inch.

Wheels are visually inspected every 8,000 miles. Visual defects are checked by AAR gauge measurement. Intermediate inspections are made in response to operator reports of rough ride quality or noisy running.

The truing machine is operated through one shift, four days a week. The fifth day is dedicated to routine servicing and cleanup. Neither trucks nor axles are removed for wheel truing. One complete car set of eight wheels is trued per day.

Approximately 200 cars, heavy and light rail, are trued per year. Table E-10 lists the categories and hourly wages of personnel involved in wheel truing and wheel changing at GCRTA.

The manpower expenditure associated with wheel truing is listed in Table E-11. An inspection and repair contract is under negotiation with the truing machine manufacturer. No cost estimates of this contract are available.

Table E-12 lists the procedures and manpower expenditures associated with wheel changing. All wheel changing is performed at Windermere Shop, where spare car sets of trucks/axles are maintained to expedite revenue car turnaround.

Table E-13 lists the annual wheel truing consumable component expenditures at GCRTA.

Table E-14 lists the equipment employed in wheel truing and wheel changing at GCRTA's Brook Park and Windermere Shops.

TABLE E-9. GCRTA HEAVY RAIL REVENUE VEHICLES

Manufacturer	Series/Type	Unloaded Weight (lbs)	Truck Type	Wheel Type	Car Purchase Date/Cost	No. of Cars
PULLMAN STANDARD	151-180	64,000	LFM Rockwell	28" Steel	1967/$177,000 1970/$220,000	30
ST. LOUIS	101-118 & 201-270 (C)	57,000	General Steel	28" Steel	1955-1958/ $80,000	18 69
					TOTAL	117

NOTES: A. All motors are self-ventilated with internal fans.

B. Brakes: Dynamic brakes down to 6 mph, air tread brakes thereafter.

C. Series 101-118 are single cars, and Series 201-270 are married pairs.

TABLE E-10. GCRTA PERSONNEL, WHEEL TRUING/CHANGING

Employee	Hourly Wage/ With Benefits	Tasks	Percent of Time Assigned Task
Special Equipment Operator Mechanic	$7.58/$11.52	Operate boring machine, press, and other special equipment.	-
Wheel Lathe Operator	7.48/ 11.37	Operate and perform routine servicing of underfloor lathe.	100
Equipment Serviceman	6.78/ 10.30	Performs varied truck shop repairs, including brake adjustments, rigging, and crane operation.	-

Wages and benefits reflect 1977 dollars.

TABLE E-11. GCRTA PERSONNEL WHEEL TRUING PROCEDURE

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (B)	Remarks
1.	TRUE WHEELS (axle set of two wheels)	2.0	1 wheel lathe operator	2.0	2.0	$22.74	Includes operation of car puller and daily servicing.
2.	ADJUST BRAKES (car set)	0.5	1 equipment serviceman	0.5	0.5	5.15	Wheel truing and adjustment performed within one 8-hour shift.

NOTES: A. Average total truing and handling time/labor costs prorated for one car set of eight wheels:

ELAPSED TIME = 8 hours; MAN-HOURS = 8.5; LABOR COSTS = $96.11.

B. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-12. GCRTA WHEEL CHANGING

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (C)	Remarks
1.	REMOVE TRUCK	1.75	2 equipment servicemen	1.75	3.5	$36.05	Typically four men work two trucks
	Prorated time/labor	0.875		0.875	1.75	18.03	For one axle set
2.	REMOVE AXLE	1.25	2 equipment servicemen	1.25	2.5	25.75	For one axle set
3.	PRESS OFF WHEELS (axle set of two wheels)	0.625	1 equipment serviceman 1 special equipment operator mechanic	0.625 1.625	0.625 0.625	6.44 7.20	Includes set-up times
4.	BORE 2 WHEELS	2.5	1 special equipment operator mechanic	2.5	2.5	28.80	For one axle set
5.	PRESS ON WHEELS (axle set of two wheels)	1.17	1 equipment serviceman 1 special equipment operator mechanic	1.17 1.17	1.17 1.17	12.05 13.48	For one axle set
6.	INSTALL AXLE	1.25	See Remarks		2.5	25.75	Reverse of REMOVE AXLE above
7.	INSTALL TRUCK	0.875	See Remarks		1.75	18.03	Reverse of REMOVE TRUCK above
	TOTAL	8.545			14.59	$155.53	

NOTES: A. Steps 1 and 2, time to remove trucks and axles, differ between GCRTA's Pullman and St. Louis cars; times listed are average values.

B. Average total wheel changing time/labor costs prorated for one car: ELAPSED TIME = 34.18 hours; MAN-HOURS = 58.35; LABOR COST = $622.12.

C. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-13. GCRTA WHEEL TRUING ANNUAL CONSUMABLE MATERIAL

Description	Cost (each)	Annual Usage/Cost	Remarks
Carbide inserts	$6.50	400/$2,600	4 index postions each; 2 inserts/ car; based on 200 cars/year capacity.
Oil (lube/hydraulic and filters)	-	less than $100	

No data on electric power consumption. Costs reflect 1977 dollars.

TABLE E-14. GCRTA WHEEL TRUING/CHANGING EQUIPMENT

Manufacturer	Series/Type	Procurement Date/Cost	Function	Remarks
HEGENSCHEIDT*	104	1976/$400,000	Underfloor wheel lathe	Includes winch type car puller, 2-ton jib crane to lift chip hoppers, templates for heavy and light rail transit car wheels.
NILES	Ser. #20428	1959/$-(used)	Bore wheels	Accommodates up to 43" wheel.
CHAMBERS	(200-ton press)	1959/$-(used)	Press wheels	--
NILES	Ser. #19262	1959/$-(used)	Wheel lathe (out of service)	Accommodates up to 33" wheel, no trace control; replaced by Hegenscheidt machine above.
STANDARD ELECTRIC TOOL COMPANY	(wheel grinder)	1955/$-(used)	Grind wheels (out of general service)	Water supply and drain; now occasionally used for axle run-out and testing gear boxes.
GLOBE	Ser. #P72254	1955/$ -	Hydraulic lift with side jacks, for raising car & removing trucks	Lifts car on upper shop level, lowers truck to lower shop level transfer table which leads to truck shop rails.
--	(5-ton crane)	1955/$ -	Moves trucks/ axles within truck shop	Installed in lower level truck/ wheel shop.

* Located at Brook Park Shop; all others at Windermere Shop.

E.3 MASSACHUSETTS BAY TRANSIT AUTHORITY

System Description

The Massachusetts Bay Transit Authority (MBTA) was formed in 1964. It serves the Boston metropolitan area with three heavy rail transit lines, a light rail line, and a bus system. The oldest subway in the system was constructed in 1897. The three heavy rail lines are operated separately, having no interconnecting track and varying facility and vehicle dimensions. A total of 333 revenue vehicles are operated on these three lines as listed in Table E-15.

The total 69.5 miles of heavy rail revenue track is approximately divided among the three lines as follows: Red Line - 31.2 miles, Orange Line - 26.1 miles, Blue Line - 12.2 miles. With the exception of some subway sections and post-1971 construction, all rail is jointed. Subsurface track is installed on wood tie and ballast. A layer of asphalt is placed over the ties and ballast in station areas to facilitate the removal of trash, discarded cigarettes, etc. Surface track is on wood tie and ballast, except for the 6.5-mile South Shore extension built in 1971 employing two-block concrete ties and ballast. Elevated track is wood ties on open deck plate girders. Direct fixation is employed on the Red Line South Shore bridges. The 4.5-mile Harvard extension will employ floating slab construction for vibration control near residential areas and sound absorbing material on tunnel walls in and around station areas. Track gauge is 4 feet, 8 inches.

Resilient or Damped Wheels

MBTA has not used resilient or damped wheels on their "heavy" transit divisions. The new light rail cars, furnished by Boeing Vertol Company, are equipped with Acousta Flex wheels.

The 120 light rail cars have 12 wheels each for a total of 1440 wheels. In the spring of 1977, two wheels experienced elastomer bonding failures which allowed the rim and tire to rotate with respect to the hub. Analysis determined that a quality control and manufacturing deficiency in one batch of approximately 50 wheels was responsible for the failures. The entire batch of wheels were subsequently replaced. No additional bonding problems have occurred.

Rail Grinding

MBTA's rail maintenance program does not include rail grinding. The most recent grinding was accomplished by contract in 1971 before opening the 6.5-mile South Shore extension. In this instance, the new track had been installed for an extended period of time before service was inaugurated and grinding was performed to improve signal performance.

Wheel Truing

Prior to the construction of the Cabot (Red Line) and Wellington (Orange Line) car houses, all MBTA wheels were trued at Everett Shop on an above floor lathe. Underfloor wheel milling machines are installed in the new car houses. Presently, Everett Shop trues all Blue Line and light rail wheels, and some from the other two lines pending resolution of manpower and equipment problems at the new car house. All wheels trued at Everett are transported to the shop by highway vehicle. No line is connected to the shop by track.

Everett Shop trues an average of 1,200 wheels per year, more than half of which are 25-inch diameter solid steel P.C.C. car wheels. A typical heavy rail wheel averages 300,000 miles before being condemned. MBTA wheels are condemned as follows: 28-inch wheels at 25.5-inch diameter, 26-inch wheels at 24-inch diameter, and the P.C.C. 25-inch wheels at 22.5-inch diameter.

Two axle sets of two wheels each are trued per eight-hour shift at Everett Shop, whereas a car set of eight wheels is trued at the car houses in the same time. Table E-16 lists the categories and hourly wages of MBTA personnel involved in wheel truing and wheel changing.

Table E-17 lists the procedure and manpower expenditures associated with wheel truing at MBTA.

Table E-18 lists the procedures and manpower expenditure associated with wheel changing.

Table E-19 lists the annual wheel truing consumable component expenditures at MBTA.

Table E-20 lists the equipment installed at MBTA employed in wheel truing and wheel changing.

TABLE E-15. MBTA REVENUE VEHICLES

Manufacturer	Series	Unloaded Weight (lbs)	Truck Type	Wheel Type	Car Purchase Date/Cost($)	Number of Cars
Pullman	1100-1199	58,080*	#2 General Steel Casting	28" Steel	1957/ 57,071	100
				ORANGE LINE	Subtotal	100
Pullman	1400-1491	70,578*	#3 General Steel Casting	28" Steel	1963/110,126	88
Pullman	1500-1523	64,462	#5 General Steel Casting	28" Steel	1969/179,165	24
Pullman	1600-1651	61,068*	#5 General Steel Casting	28" Steel	1969/165,072	52
				RED LINE	Subtotal	164
Pullman	0501-0539#	49,000	Taylor	26" Steel	1923/ 26,633	28
Pullman	0540-0547#	44,000	Taylor	26" Steel	1924/ 27,533	4
St. Louis	0548-0587	48,000	Clark B-10	28" Steel	1951/ 49,557	37
				BLUE LINE	Subtotal	69
					SYSTEM TOTAL	333

* Series consists of A and B cars, weight listed is average.

Even numbered cars incorporate pantograph.

Notes: A. All motors incorporate self-ventilating fan.

B. Brakes: All cars except 0501-0547 series have dynamic braking followed by tread braking. 0501-0547 series cars employ air brakes.

TABLE E-16. MBTA PERSONNEL WHEEL TRUING/CHANGING

Employee	Hourly/ With Wage/Benefits	Tasks	Percent of Time Assigned Tasks
Car House Repairman	$8.38/$12.57	Operate truing machine and car progression system, routine servicing, remove/ install trucks and axles.	20 (Red Line) 5 (Orange Line) -
Everett Shop			
Machinist	9.50/ 14.25	Operate/set up lathe, operate press and boring machine.	100 -
Machine Specialist	9.40/ 14.10	Assist in operating wheel press.	-
Driver	8.30/ 12.45	Operate highway vehicle between car houses and Everett Shop.	-
General Helper	7.93/ 11.90	Operate forklift, degrease axle sets.	- -

Wages and benefits reflect 1977 dollars.

TABLE E-17. MBTA WHEEL TRUING PROCEDURE

Step Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (E)	Remarks
CABOT & WELLINGTON CAR HOUSES 1. TRUE WHEELS (one car set of eight wheels)	8.0	1 car house (C.H.) repairman	8.0	8.0	$100.56	includes operation of car progression system and daily servicing.
EVERETT SHOP						
1. REMOVE TRUCK	1.75	2 C.H. repairmen	1.75	3.50	$ 44.00	at car house
Prorated Time/Labor	.875		.875	1.75	22.00	per axle set
2. REMOVE AXLE	2	2 C.H. repairmen	2	4	50.28	per axle set
3. TRUE 2 WHEELS	4	1 machinist	4	4	57.00	includes rigging
4. INSTALL AXLE	2	2 C.H. repairmen	2	4	50.28	per axle set
5. INSTALL TRUCK	2	2 C.H. repairmen	2	4	50.28	
Prorated Time/Labor	1			2	25.14	per axle set
6. TRANSPORT AXLE						
a. within Everett	.25	1 general helper	.25	.25	2.97	by forklift
b. outside shop	1.5	1 driver	1.5	1.5	18.67	by highway vehicle

NOTES:
A. Steps 1, 2, 4, & 5 accomplished at car house.
B. Step 6.b., transporting axle outside shop, between car house and Everett Shop is the same cost for one axle set or one car set.
C. Average total truing and handling time/labor costs prorated for one axle set of 2 wheels: ELAPSED TIME = 11.6 hours; MAN HOURS = 17.5; LABOR COST = $226.34.
D. Average total truing and handling time/labor costs prorated for one car set of 8 wheels: ELAPSED TIME = 42 hours; MAN HOURS = 73.5; LABOR COST = $849.35.
E. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-18. MBTA WHEEL CHANGING

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (D)	Remarks
1.	REMOVE TRUCK	.875	2 C.H. repairmen	.875	1.75	$ 22.00	per axle set
2.	REMOVE AXLE	2	2 C.H. repairmen	2	4	50.28	per axle set
3.	CLEAN AXLE	.25	1 general helper	.25	.25	2.98	steam degrease
4.	PRESS OFF WHEEL	1.5	1 machinist	1.5	1.5	21.37	per axle set
	(axle set of 2 wheels)		1 mach. specialist	1.5	1.5	21.15	includes rigging
5.	BORE 2 WHEELS	3	1 machinist	3	3	42.75	one axle set
6.	PRESS ON WHEELS	2	1 machinist	2	2	28.50	per axle set
	(axle set of 2 wheels)		1 mach. specialist	2	2	28.50	includes rigging
7.	INSTALL AXLE	2	2 C.H. repairmen	2	4	50.28	per axle set
8.	INSTALL TRUCK	1	2 C.H. repairmen	1	2	25.14	per axle set
9.	TRANSPORT AXLE & WHEELS						
	a. within shop	.5	1 general helper	.5	.5	5.95	by forklift
	b. outside	1.5	1 driver	1.5	1.5	18.67	by highway vehicle
TOTAL		14.63			24.0	$317.27	for one axle set

NOTES:
A. Steps 1, 2, 7, & 8 accomplished at car house.
B. Step 9.b., transporting axle outside shop, between car house and Everett Shop is the same cost for one axle set or one car set.
C. Average total wheel changing time/labor costs prorated for one car: ELAPSED TIME = 54 hours; MAN-HOURS = 91.5; LABOR COST = $1,213.07.
D. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-19. MBTA WHEEL TRUING ANNUAL CONSUMABLE MATERIAL

Description	Cost (each)	Annual Usage/Cost	Remarks
Carbide tips (Everett Shop)	$17.70	106/$1,876.12	Usage has been decreasing over the past four years, (492-398-250-106) but correlating number of wheels trued is not available.
Carbide inserts (car houses)	2.05	--	Average two inserts per two-wheel axle set.

No data on electric power or oil consumption. Costs reflect 1977 dollars.

TABLE E-20. MBTA WHEEL TRUING/CHANGING EQUIPMENT

Manufacturer	Series/Type	Procurement Date/Cost	Function	Remarks
Niles	(24" to 42" wheels)	1965 (used)/$80,000	above floor wheel lathe	Converted gearing and tracers
Dake	(600 ton)	1976/$37,000	wheel press	--
Niles	--	1965/$40,000	bore wheels	--
(various cranes at Everett Shop)	(3 ton) (6 ton) (12 ton)	--/$-- --/$-- --/$--	lift axle sets lift trucks various	-- -- --
Stanray	ser. #70200484 ser. #70200485	1975/$-- 1973/$265,000	under floor wheel lathes	At Cabot and Wellington car houses; include car progression systems, 2 jib cranes, vacuum waste removal
(car house - crane)	(7½ ton)	--/$--	axle removal	--
(car house - jacks)	--	--/$--	truck removal	hydraulic floor jacks with turntable

E.4 NEW YORK CITY TRANSIT AUTHORITY

System Description

The New York City Transit Authority (NYCTA) assumed operation and control of all transit systems within the city in 1953. Rail operations are divided in two division. "A" Division includes the IRT line, which opened in 1904. "B" Division includes the BMT and IND lines which opened in 1913 and 1932 respectively. Although both divisions operate on standard 4 feet,8½ inches gauge track, services are separated because of clearance restrictions. "A" Division cars are approximately 9 feet wide and 50 feet long. "B" Division cars are 10 feet wide and 60 and 70 feet long.

The system operates 24 hours per day throughout the year on some 703 miles of revenue track. This track is comprised of 75 miles of surface track, 170 miles of elevated track, and 449 miles of subway track. A total of 6,674 revenue cars, listed in Table E-21, operate an average of 50,000 miles per year each.

Resilient Wheels

NYCTA tested three types of resilient wheels between March 1947 and September 1947. The wheels were manufactured by Clark Equipment Company, Carnegie Illinois Steel Corporation, and the National Malleable and Steel Company. At the conclusion of the test period, NYCTA decided not to purchase any of these wheels.

NYCTA has no experience with the types of resilient wheels being tested in this program.

Rail Grinding

NYCTA grinds rail primarily to extend rail life. Noise reduction is a secondary benefit. Rail grinding is performed on a schedule based upon the history of rail conditions, visual inspections, and use of the F-116 Rail Inspection Car. Some 350 track miles are ground annually, primarily on curves and in station areas. NYCTA does not grind elevated track due to sparks and slag from grinding operations. Most elevated structures run above public thoroughfares.

The F-116 Rail Inspection Car, designed and built by NYCTA from a used bus body, measures alignment, gauge, surface, and corrugation. It operates twice weekly. Traveling at 20 miles per hour, it traverses the entire system twice annually.

NYCTA utilizes a customized SPENO rail grinder with 48 rotary stones on each rail. This unit grinds at 1.25 miles per hour, removing approximately 0.010 inches of rail surface with each pass. Typically, three passes are made over sections to be ground. The grinder had been rented until 1970, at which time it was purchased for $1,000,000.

NYCTA provides 24-hour revenue service daily throughout the year. Grinding is conducted during off-peak hours, 11 p.m. to 7 a.m. Development of corrugation is most pronounced on curved track especially where subjected to braking action as at curved approaches to stations.

Experiments conducted by NYCTA indicate that no appreciable noise reduction is achieved in tunnels or trains by grinding rails; however, as much as 10 dB noise reduction has been achieved in buildings adjacent to the subways after grinding corrugated rail.

The total annual cost for rail grinding at NYCTA is $500,000 apportioned as follows: manpower - $355,000; equipment - $19,500; support labor - $125,000.

<u>Wheel Truing</u>

NYCTA has been using underfloor milling machines for truing wheels since 1957. Two machines are installed at the Concourse Yard, one at the Coney Island Yard and a fourth machine is installed at the 207th Street Yard. Approximately 20,000 axle sets are trued annually.

The 34-inch diameter solid steel wheels at NYCTA have an average 300,000-mile life. They are inspected at 7,500-mile intervals and trued whenever a reading of "4" or above is measured with the AAR Wheel Gauge No. 714-W-11. Wheels are

condemned whenever rim thickness is less than one inch, which is two inches of diameter wear.

NYCTA records indicate that truing does not decrease wheel wear. Truing flat spots 1 inch to 1½ inches long does appear to reduce noise by as much as 10 dBA and vibration transmitted to subway structures by 10 dB. The slip slide controls on R-44 and R-46 cars result in a 50 percent lower incidence of flat spots than cars not so equipped. Thirty older cars retrofitted with an experimental "antiflat" mechanism, which prevents simultaneous application of mechanical and dynamic brakes, resulted in a 50 percent reduction in flat spot occurrence during a two-year test. During nearly nine years of noise measurements in the NYCTA system, the Authority's Environmental Staff Division estimates that 30 percent of the cars have "spotted" wheels that are 5 to 10 decibels noisier than smooth wheels, although the spots are not large enough to require truing. The installation of a brake mechanism retrofit and a reduction in the size of allowable flat spots from 1½ inches to 1 inch has significantly reduced the number of spotted wheels in revenue service. The following standards are now used for reporting flat wheels for truing:

1. Any wheel with a flat spot of 1 inch or greater in length shall be reported for immediate truing.
2. Any wheel with a series of flat spots of 3/4 inch to 1 inch in length in which the total length of all spots in one quadrant (1/4 of the total circumference) of the tread is 4 inches or greater shall be reported for truing as soon as practical.

The manpower associated with the wheel truing operation at the Coney Island Yard is listed in Table E-22. The wheel truing machine at the Coney Island Yard is operated 24 hours per day. At the Concourse Yard, the two wheel truing machines are operated 3 eight-hour shifts, five days per week. Two above-floor lathes are also available for wheel truing.

TABLE E-21. NYCTA REVENUE VEHICLES

MANUFACTURER	SERIES	UNLOADED (7) WEIGHT (LBS)	TRUCK TYPE (2)	WHEEL TYPE	CAR PURCHASE DATE/COST($)	NUMBER OF CARS	DIVISION
A.C.F.	R-10	N.A.	General Steel	34"steel	1946/ 77,319	400	B
Budd	R-11	"	Clark/Gen. Steel	"	1947/121,373	10	B
A.C.F.	R-12	"	General Steel	"	1946/ 71,487	100	A
A.C.F.	R-14	"	General Steel	"	1947/ 74,748	150	A
A.C.F.	R-15	"	General Steel	"	1947/ 77,587	100	A
A.C.F.	R-16	"	General Steel	"	1953/121,442	200	B
St. Louis	R-17	"	General Steel	"	1954/103,533	400	A
St. Louis	R-21	"	General Steel	"	1955/102,898	250	A
St. Louis	R-22	"	General Steel	"	1956/106,699	450	A
A.C.F.	R-26*	"	General Steel/ Adirondack Steel	"	1958/107,157	110	A
St. Louis	R-27*	"	General Steel/ Adirondack Steel	"	1959/119,227	230	B
A.C.F.	R-28*	"	General Steel/LFM	"	1959/114,495	100	A
St. Louis	R-29*	"	General Steel	"	1961/110,842	236	A
St. Louis	R-30*	"	General Steel/ Adirondack/LFM	"	1960/121,663	260	B
St. Louis	R-30A*	"	General Steel	"	1960/121,563	60	B
Budd	R-32*	"	General Steel/ Adirondack	"	1963/114,951	300	B
Budd	R-32A*	"	General Steel/ Adirondack/LFM	"	1963/114,857	300	B
St. Louis	R-33**	"	General Steel	"	1962/108,500	540	A
St. Louis	R-36*	"	General Steel	"	1962/110,563	424	A
St. Louis	R-38*	"	General Steel/ Adirondack	"	1965/111,773#	200	B
St. Louis	R-40*	"	General Steel/ Adirondack	"	1966/115,517	200	B
St. Louis	R-40(AC)*	"	C.S.I./Adirondack	"	1966/137,382	200	B
St. Louis	R-42*	"	C.S.I./Adirondack	"	1968/132,670	400	B
St. Louis	R-44@	"	C.S.I./Adirondack	"	1970/211,850	300	B
Pullman (4)	R-46@	"	Rockwell	"	1972/275,381	754	B
Subtotals: Division A = 2,860; Division B = 3,814.					TOTAL	6,674	

TABLE E-21.

Legend:

N.A.	= Not available	A.C.F.	= American Car & Foundry
*	= Two-car unit	(AC)	= Air conditioned
**	= 40 single cars	@	= four-car unit, slip slide control
#	= 10 cars with air conditioning, 154,423 each		

Notes:

(1) Division - A = IRT line; B = BMT & IND lines.

(2) All trucks are cast steel equalized outboard journal;

(3) R-46 series also has articulated frame.

(4) 390 A cars, 364 B cars

(5) Brakes = dynamic brakes down to 7 mph, electro pneumatic tread brakes thereafter.

(6) All motors are self-ventilated with internal fans.

(7) Cars weigh between 100,000 and 120,000 lbs. unloaded.

TABLE E-22. NYCTA PERSONNEL UNDERFLOOR TRUING MACHINE

Employee	Hourly/ With Wage/Benefits	Tasks	Percent of Time Assigned Task
Machinist	$7.23/	Prepare car, true wheels	100
Truck Mechanic	7.23	Adjust/change brake shoes, adjust trip cock/car body height	100
Shop Serviceman	6.06	Clean out chip chute and machine area	10

Wages reflect 1977 dollars.

E.5 PORT AUTHORITY TRANSIT CORPORATION

System Description

The Port Authority Transit Corporation (PATCO) inaugurated service in 1969, connecting south New Jersey suburban communities with Philadelphia. It operates 75 revenue vehicles, listed in Table E-23, approximately four million car miles per year.

The 28.4 miles of revenue track include: 21.6 miles of surface and 2.0 miles of bridge track consisting of 132-pound ASCE welded rail on wood tie and ballast and 4.8 miles of subway track consisting of 100-pound ASCE jointed rail on wood half ties imbedded in concrete. Track gauge is 4 feet, 8 inches.

Two inches of acoustical insulation has been applied under the Franklin Square Station platform with a reported perceivable reduction of noise. No acoustical measurements are available.

Rail lubricators are installed on curved track sections, some with radii of 200 feet. The lubricators have exhibited a tendency to malfunction.

Resilient Wheels

In 1974, PATCO tested a set of eight BOCHUM resilient wheels on one car. After three days of service, one truck was removed after the wheels had become overheated as a result of a hand brake being applied. The other truck set remained in service for six months. Boeing Vertol made sound recordings. From this test, PATCO concluded that:

a. The BOCHUM wheels eliminated wheel squeal on curves.
b. There is little difference in acoustical characteristics between BOCHUM and monoblock steel wheels along tangent track.

c. The possibility exists of overheating the rubber blocks with tread brakes, especially if given a dynamic brake failure at 75 mph on PATCO's 78,000-pound Budd car.

d. BOCHUM wheels cannot be used with Budd car Pioneer III restrained center pivot trucks. With this type truck, the tire restraining flange strikes the wheel hub before the car begins to turn into a curve. PATCO observed marks on the flange from striking facing frogs on curves. Lateral flexibility allowed wheels to be out of gauge on curves.

   Note: The manufacturer has subsequently developed and patented a design (December 1976) to reduce this lateral displacement. Tests of this new design in Germany indicate axial spring travel and wheel track change do not exceed 2 millimeters, noting 1 mm is experienced by solid steel wheels.

e. The copper shunt strap connecting hub to tire showed signs of fatigue, probably from side motion resulting from (d) above.

Ring Damped Wheels

PATCO installed a car set of ring damped wheels in 1975. Boeing Vertol modified a set of PATCO standard steel wheels for this application. Subsequently, five additional car sets of ring damped wheels were put into service, PATCO having modified standard steel wheels in-house. The rings, manufactured locally of cold rolled round stock at a cost of approximately $8 each, were locked in the wheel grooves by means of a plug welded to the ends of the ring. Boeing Vertol made sound recordings of the original ring damped car set and standard wheels. PATCO's conclusions on ring damped wheels were:

a. Wheel squeal on curves is dramatically reduced to a low pitch growl.

b. Other qualities of the ring damped wheel are comparable to those of a standard steel wheel.

Although PATCO experienced no operating problems, installation of dampening rings was suspended in September, 1976 after nine cars were equipped when a PATCO consultant advised that machining of the groove into the shot-peened surface of the wheel may tend to weaken the wheel.

<u>Rail Grinding</u>

Prior to commencement of revenue service, PATCO contracted the grinding of all track to assure good shunting. In 1971, and approximately every two years thereafter, rail grinding services have been contracted for all revenue track. Grinding is performed primarily to reduce noise. There is no measurement or fixed schedule applied to this program. The Superintendent of Way and Power determines the need for grinding based on his inspection of rail corrugation.

Rail corrugation is most pronounced on curves, expecially the 200-foot radius curves near City Hall and Ninth Street stations. This corrugation had been more severe with the line's original 113,000-pound cars on 36-inch steel wheels. Approximately 280,000 revenue cars pass over the revenue track between grindings. Rail wear over the nine years of system operation is approximately 5 percent with the present rail grinding program.

Though guard rails tend to chip/break grinding stones, there are no major restrictions on rail grinding. Occasional grass fires along surface track does not warrant water spray provisions. Grinding dust in subways is removed during routine and annual cleanup.

Typically, a SPENO bus power unit and several buggies, with two dozen grinding stones, is contracted to grind all revenue rail in sixty hours over seven days. The grinder operates at approximately one mph and usually requires two passes to accomplish the task. Approximately 0.0015 inches of rail surface is removed with each pass. Single track operation is necessary during grinding. The grinding train has exclusive occupancy of only one traffic block.

By performing all weekday and Saturday grinding at night, only Sunday service schedules are affected. Sunday headways are extended from 15-minute to 24-minute intervals.

The cost of the 1977 rail grinding contract will be approximately $12,000. This contract includes the rail grinding equipment, all operating personnel and consumable materials.

Additionally, PATCO assigns a foreman to coordinate use of track, deenergize third rail and perform liaison/witnessing functions. At $13 an hour (including benefits), this expenditure amounts to $910, including overtime.

No support facilities or equipment are required.

<u>Wheel Truing</u>

PATCO has maintained a wheel truing program since system start up, utilizing an above floor wheel lathe which accommodates a complete truck. Both solid steel wheels and ring damped wheels are trued. Wheels are visually inspected whenever noise is reported and at each scheduled car inspection: monthly and at 12,000-mile intervals. They are checked with AAR wheel gauges at the 50,000-mile inspection or whenever visual inspection indicates irregular wear. A typical wheel is trued every 55,000 to 70,000 miles (every 12 to 14 months), averaging four truings over a typical 240,000 to 300,000-mile life.

Wheels are trued to 0.003 inch tolerance between wheels on the same axle. All wheels on a car are required to be within 0.5 inch diameter. PACTO condemning limit is 25.5 inch diameter.

Additionally, small dime size flat spots are frequently removed with abrasive shoe brakes. Typically, a mechanic changes the brake shoes in the shop and operates the car within the yard up to 30 mph with dynamic braking disconnected. This effort spans two hours, one hour in actually running the car and the remaining changing brake shoes and disconnecting/connecting dynamic braking.

All wheels at PATCO are trued in the Lindenwold Shop. Table E-24 lists the categories and hourly wages of personnel involved in wheel truing and wheel changing at PATCO.

The procedures and manpower expenditures associated with wheel truing are listed in Table E-25. Typically two truck sets are trued in an eight-hour shift.

Table E-26 lists the procedures and manpower expenditures associated with wheel changing.

Table E-27 lists the annual wheel truing consumable component expenditures at PATCO. In addition to routine preventive maintenance, the above floor lathe receives an average two to five days of service repairs every two years, contracted at a cost of approximately $4,000, including material and labor (1977 dollars).

Table E-28 lists the equipment installed at PATCO's Lindenwold Shop employed in wheel truing and wheel changing.

TABLE E-23. PATCO REVENUE VEHICLES

Manufacturer	Series	Unloaded Weight (lbs)	Truck Type	Wheel Type	Car Purchase Date/Cost	Number of cars
Budd Company	101-125	78,000	Pioneer III	28" Steel	1968/$192,000	25
Budd Company	201-250	74,000	Pioneer III	28" Steel	1968/$189,000	50 (married pairs)

NOTES: A. All motors incorporate self-ventilating fans.

B. Brakes: dynamic braking to 15 mph; air brakes, tread brakes below 10 mph.

C. All cars incorporate slip-slide protection system.

TABLE E-24. PATCO PERSONNEL WHEEL TRUING/CHANGING

Employee	Hourly/ With Wage/Benefits	Tasks	Percent of Time Assigned Task
Foreman	$10.00/$13.00	Operate lift for detrucking	-
Electrician	6.86/ 8.92	Disconnect/reconnect trucks; disconnect/reconnect motors	2
Machinist	6.69/ 8.70	Qualified on wheel lathe; qualified on press/boring machine	10 -
Mechanic	6.69/ 8.70	Detruck, operate overhead crane; qualified to set up segmented abrasive brake shoes/operate car	5 5
Yard Motorman	6.53/ 8.49	move disconnected car around yard/shop with other available car	-
Helper	5.49/ 7.14	Qualified on overhead crane and assists at lathe set up	5

Wages and benefits reflect 1977 dollars.

TABLE E-25. PATCO WHEEL TRUING PROCEDURE

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (C)	Remarks
1.	REMOVE TRUCKS						
	a. Receive car over pit . disconnect trucks	1	1 electrician 2 mechanics	0.5 1	0.5 2	$ 4.46 17.40	Working both trucks at same time
	b. Move car to lifting bay	1	1 yard motorman 2 mechanics	1 1	1 2	8.49 17.40	Use another revenue vehicle as available to push/pull
	c. Raise car on lift	2	1 shop foreman 2 mechanics	1 2	1 4	13.00 34.80	Foreman operates lift
	Subtotal	4			10.5	95.55	For two trucks
	Prorated time/labor	2			5.25	47.78	For one truck
	Prorated time/labor	1			2.63	23.89	For one axle
2.	TRUE WHEELS (TRUCK SET OF FOUR WHEELS)						
	a. Set up one axle set of truck in lathe	0.5	1 machinist 1 helper	0.5 0.5	0.5 0.5	4.35 3.57	Either man operates crane
	b. Turn one axle set	1.25	1 machinist	1.25	1.25	10.88	Operate lathe
	c. Reverse truck to set up other axle set	0.5	1 machinist 1 helper	0.5 0.5	0.5 0.5	4.35 3.57	Either man operates crane
	d. Turn one axle set	1.25	1 machinist	1.25	1.25	10.88	
	e. Remove truck from lathe	0.5	1 machinist 1 helper	0.5 0.5	0.5 0.5	4.35 3.57	
	f. Sharpen lathe tools	2	1 helper	2	2	14.28	Normally sharpens four sets for two cars during one day
	Subtotal	4			7.5	59.60	For one truck set
	Prorated time/labor	2*			3.75	29.80	For one axle set

TABLE E-25.
PATCO WHEEL TRUING PROCEDURE (Continued)

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (C)	Remarks
3.	REINSTALL TRUCKS (reverse procedure of REMOVE TRUCKS above)						
	Subtotal	4			10.25	$95.55	For two trucks

NOTES: A. Average total truing and handling time/labor costs prorated for one axle set of two wheels: ELAPSED TIME* = 4 hours; MAN-HOURS = 9; LABOR COST = $77.58.

B. Average total truing and handling time/labor costs prorated for one car set of eight wheels: ELAPSED TIME* = 16 hours; MAN-HOURS = 36; LABOR COST = $310.30.

C. Labor costs include hourly wage with benefits and reflect 1977 dollars.

* Elapsed Time totals do not include tool sharpening since it does not interfere with truing/handling evolution; man hours and labor cost totals do include tool sharpening.

TABLE E-26. PATCO WHEEL CHANGING

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (C)	Remarks
1.	REMOVE TRUCK	1.0	See Table --		2.63	$23.89	Prorated for one axle set
2.	REMOVE AXLE	2.0	1 electrician 2 mechanics	0.5 2.0	0.5 4.0	4.46 34.80	Electrician discon-nects/removes motor; mechanics operate crane
3.	CLEAN AXLE	1.0	1 helper	1.0	1.0	7.14	Scrapes and steam cleans outside shop on drainage slab
4.	PRESS OFF WHEELS (axle set-2 wheels)	1.0	1 machinist 3 mechanics	1.0 1.0	1.0 3.0	8.70 26.10	Machinist operates press; most of this time is handling
5.	BORE WHEEL (axle set-2 wheels)	2.0	1 machinist 1 helper	2.0 0.5	2.0 0.5	17.40 3.57	Operates boring machine; assists handling wheel
6.	PRESS ON WHEEL (axle set-2 wheels)	1.5	1 machinist 3 mechanics	1.5 1.5	1.5 4.5	13.05 39.15	Machinist operates press; most of this time is handling
7.	INSTALL AXLE	2.0	See remarks	-	4.5	39.26	Reverse of REMOVE AXLE above
8.	INSTALL TRUCK	1.0	See remarks	-	2.63	23.89	Reverse of REMOVE TRUCK above
	TOTAL	11.5			27.76	$241.41	For one axle set

TABLE E-26.

NOTES: A. Normally, after axle removal/cleaning, PATCO also renovates journal bearing and magnifluxes axle; no time/cost data.

B. Average total wheel changing time/labor costs prorated for one car: ELAPSED TIME = 46 hours; MAN HOURS = 111.04; LABOR COST = $965.64.

C. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-27. PATCO WHEEL TRUING ANNUAL CONSUMABLE MATERIAL

Description	Cost (each)	Annual Usage/Cost	Remarks
Segmented grinding shoes	$ 6.34	408/$2,586.72	8 per car; A.P. De Santo & Son, Type 7RA201-G2VOS
Lathe tools*			
Roughing, carbide	6.46	88/$568.40	disposable
Roughing, steel	21.30	8/$170.40	-
Throat	57.06	4/$228.24	right and left hand
Flange	58.50	4/$234.00	right and left hand
Profile	90.12	6/$540.72	right and left hand
Total for lathe tools		$1,741.84	for 140 axle sets

Costs reflect 1977 dollars.

No data on electric power or oil/filter consumption.

* Tools are purchased in small lots of 2 to 6 pieces.

TABLE E-28. PATCO WHEEL TRUING/CHANGING EQUIPMENT

Manufacturer	Series/Type	Procurement Date/Cost	Function	Remarks
Sellers Co.	(50" wheel lathe)	1970 (used)/20,000 (Built 1941)	above floor wheel lathe	Accepts complete truck, turn one axle at a time
Browne & Sharpe Mfg. Co.	No. 2	1973 (used/$700 (Built approx. 1953)	grinder to sharpen lathe tools	-
Tomline & Harris Machine Co.	-	1973 (used/$ - (Built 1899)	200-ton wheel press	1976 replaced pump 1977 rebored/relined
Bullard	(36" vertical turret)	1968/$ - (Built 1943)	bore wheels	-
Cleveland Beacon Products Co.	(17.5-ton crane) (5-ton crane	1968/$25,000 1969/$10,000	lift trucks or cars lift truck to lather	- -
Globe Wayne	40-ton hydraulic lift	1968/approx. $100,000	lift cars for detrucking	two per car; will retire in 1977 due to unrelia-bility; replace with screw jacks
Joyce Cridlind Co.	25-ton (screw jacks)	1977/$56,000 set of eight	lift cars for detrucking	-
Whiting Corp.	35-ton (screw jacks)	1973/$15,000 set of four	lift car	-

NOTE: A pit is necessary for access to disconnect truck from car due to car design restrictions.

E.6 PORT AUTHORITY TRANS-HUDSON CORPORATION

System Description

The Port Authority Trans-Hudson Corporation (PATH) was founded in 1962 to operate and modernize the Hudson and Manhattan Railroad serving northern New Jersey and New York City since 1908. It operates 298 revenue vehicles, listed in Table E-29, approximately nine and a half million car-miles per year. The K series cars average 18,000 miles per year; the PA series cars average 35,000 miles per year.

The 28.4 miles of revenue track include: 12.6 miles of surface track consisting of 119-pound AREA jointed rail on wood tie and ballast, except for Neward Station, where rails are mounted on wood blocks which are bolted to the concrete slab; 15.8 miles of subway track consisting of 100-pound ARA-B jointed rail on wood tie and ballast (80 percent) and 20% of half length wood tie mounted on concrete slab, including the World Trade Center. Track gauge is 4 feet, 8½inches.

Acoustical spray treatment of subway walls and under platforms has been initiated.

Both manual and automatic rail lubrication is employed on curves of 10 degrees or more and at junctions, crossovers and caissons. The minimum revenue track curve radius is 115 feet. Manual lubrication is only applied to the side of the check (guard) rail. Automatic lubrication is applied to the side of the lower guard rail and the inside of the high rail.

Typical noise levels experienced on the PATH system are:

a. Running at 30 mph on jointed track, 88 dBA (ambient, 64-68 dBA)[at wayside 50 ft. from track]
b. Braking in station area, 89-94 dBA (14th Street Station, 6½ feet from platform's edge)
c. Accelerating in station area, 82-86 dBA (14th Street Station, 6½ feet from platform's edge)
d. On 148-foot curve, 93-94 dBA (inside car)

Damped Wheels

In 1967, PATH tested Soundcoat constrained layer ring damping treatment on 18 wheels. Two wheels were run in normal revenue service for five months. Another 16 wheels on two cars were run for 1,000 miles.

In November 1967, the two cars with damped wheels and two cars with untreated solid steel wheels were monitored for noise at three locations with the following results:

a. Inside a station, Hudson Terminal, with 90-foot radius curves*- at 5 mph the damped wheel cars generated 81 dBA versus 105 dBA from the untreated wheel cars. The damped wheel cars did not have screech noise peaks at 500 and 2,000 Hz as did the untreated cars.
b. In the open, (Henderson Street Yard) through a turn-around - at 5 mph the untreated car noise was 108 dBA versus 70 dBA from the damped wheel cars; at 15 mph the untreated car noise was 120 dBA versus 89 dBA from the damped wheel cars.
c. In a tunnel with sharp curve, (near Pavonia Station) - at slow speed the untreated car noise was 115 dBA versus 93 dBA from the damped wheel cars; at high speed the untreated car noise was 118 dBA versus 102 dBA from the damped wheel cars.

The difficulties experienced with these wheels were:

1. Adhesion failure allowing rings to fall off along tracks. Since rings were assembled in the shop with "C" clamps, control of bonding of rings to the wheels was marginal.
2. Rings interfered with wheel lathe holding jaws during turning operations.
3. Visual inspection was prohibited because wheel was covered with damping material.

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* Curves were eliminated as a result of World Trade Center construction.

Rail Grinding

PATH does not have a rail grinding program as corrugation is not a problem on any of the system's tracks. However, in 1966 and 1967 the Authority did contract for grinding services on three and a half miles of newly installed track which had weathered in storage. The purpose for grinding was to assure good electrical contact and provide for good ride quality.

A Speno grinder with contouring stones was contracted. PATH provided all consumables plus a pilot and watchman. After grinding, a perceivable reduction in noise was reported.

Conditions which could restrict grinding on the PATH system include third rail clearances and guards on sharp turns interfering with stones.

The estimated rail life at PATH is 7-10 years on curves, 15-17 years in platform areas and 22 years on tangent track.

Wheel Turning

PATH has utilized an above floor lathe for turning wheels since inaugurating service. An axle set of two wheels is accepted by this lathe. Approximately 300 axle sets are turned per year. Wheels are visually inspected daily and at 50-day intervals. Irregularities visually detected are checked with AAR gauges to assess need for turning. Flats are not allowed to exceed 1½ inches. Adjacent flats are not allowed to exceed 1 inch. Wheels having flanges of 31/32 inch or less are turned. Wheels having rims 1" thick or less are not turned. No schedule for turning wheels is established.

Wheels on "K" series cars have a life of approximately 350,000 miles. Wheels on PA series cars have a life between 150,000 and 250,000 miles. Typically, the average wheel is turned three times before condemnation at 26 inches.

All wheels are turned at PATH's Henderson Street Shop. Twenty worked axle assemblies are maintained on hand to replace removed axle sets without delaying cars for wheel/axle repairs. Typically, the lathe will be operated no more than three days in a week depending on usage of stocked sets. An average of six axle sets of two wheels are turned in an eight-hour shift.

Table E-30 lists the categories and hourly wages of personnel involved in wheel truing and wheel changing at PATH.

The procedures and manpower associated with this operation are listed in Table E-32.

Table E-32 lists the procedures and manpower expenditures associated with wheel changing.

Table E-33 lists the annual wheel truing consumable component expenditures at PATH.

Table E-34 lists the equipment installed at PATH's Henderson Street Shop employed in wheel truing and wheel changing evolutions.

TABLE E-29. PATH REVENUE VEHICLES

Manufacturer	Series	Unloaded Weight (lbs)	Truck Type	Wheel Type	Car Purchase Date/Cost	Number of Cars
St. Louis	K	70,000	GSI	28" Steel	1957/$ 95,000	47
St. Louis	PA1	58,500	GSI70	28" Steel	1964/$110,000	161
St. Louis	PA2	58,500	GSI70	28" Steel	1966/$125,000	44
Hawker-Siddeley	PA3	60,000	GSI70C	28" Steel	1970/$185,000	46
					Total	298

Notes: A. All motors are self-ventilated with internal fans.

B. Brakes: dynamic brakes down to 8-10 mph for PA1, 2 and 3; 4-6 mph for k cars, and tread brakes thereafter.

TABLE E-30. PATH PERSONNEL WHEEL TURNING/CHANGING

Employee	Hourly / With Wage / Benefits	Tasks	Percent of Time Assigned Task
Lead Machinist	$7.81/$11.40	Supervises pressing operations	-
Car Repairman	7.50/ 10.95	Disconnect trucks, removes trucks/axles	-
Crane Operator	7.50/ 10.95	Lift car/axle set with crane	-
Machinist	7.50/ 10.95	Sets up and operates lathe, boring machine, and press	-
Helper	5.88/ 8.58	Assists car repairman	-

Wages and benefits reflect 1977 dollars.

TABLE E-31. PATH WHEEL TURNING PROCEDURE

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (D)	Remarks
1.	REMOVE TRUCK	0.33	1 crane operator	0.25	0.25	$ 2.74	Lift car with crane; set on horses
			1 helper	0.33	0.33	2.83	
			2 car repairmen	0.33	0.67	7.34	
	Subtotal	0.33			1.25	12.91	For one truck
	Prorated time/labor	0.167			0.625	6.46	For one axle set
2.	REMOVE AXLE	1.17	1 crane operator	0.25	0.25	2.74	
			2 car repairmen	1.17	2.34	25.62	
			1 helper	1.17	1.17	10.04	
	Subtotal	1.17			3.76	38.40	For one axle set
3.	TRUE WHEEL (axle set of 2 wheels)	0.75	1 machinist	0.75	0.75	8.21	Includes set up and unrig with jib crane
4.	REINSTALL AXLE	1.17	see remarks		3.76	38.40	Reverse of REMOVE AXLE above
5.	REINSTALL TRUCK	0.33	see remarks		1.25	12.91	Reverse of REMOVE TRUCK above

NOTES:

A. Not accounted for above is removal of motors from K series car axles before turning. PA series cars are turned on lathe with motor on axle.

B. Average total truing and handling time/labor costs prorated for one axle set of two wheels: ELAPSED TIME = 3.42 hours; MAN HOURS = 9.52; LABOR COST = $97.93.

C. Average total truing and handling time/labor costs prorated for one car set of eight wheels: ELAPSED TIME = 13.68 hours; MAN HOURS = 38.08; LABOR COST = $391.68.

D. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-32. PATH WHEEL CHANGING

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (C)	Remarks
1.	REMOVE TRUCK	0.167	See Table		0.625	$ 6.46	Prorated for one axle set
2.	REMOVE AXLE	1.17	See Table		3.76	38.40	For one axle set
3.	PRESS OFF WHEEL	1.0	1 crane operator	0.5	0.5	5.48	
			1 lead machinist	1.0	1.0	11.40	
			2 machinists	1.0	2.0	21.90	
	Subtotal	1.0			3.5	38.78	For one wheel
	Prorated time/labor	2.0			7.0	77.56	For one axle set
4.	BORE WHEEL	1.0	1 machinist	1.0	1.0	10.95	Includes handling
	Prorated time/labor	2.0			2.0	21.90	For one axle set
5.	PRESS ON WHEEL	1.0	see remarks		3.5	38.78	Reverse of PRESS OFF WHEEL above
6.	INSTALL AXLE	1.17	see remarks		3.76	38.40	Reverse of REMOVE AXLE above
7.	INSTALL TRUCK	0.167	see remarks		0.625	6.46	Reverse of REMOVE TRUCK above
	Total	8.670			24.770	$266.74	For one axle set

NOTES: A. Axles are not typically steamed or scraped clean after removal from truck, but axles are magnifluxed when wheels are removed. No time/cost data.

B. Average total wheel changing time/labor costs prorated for one car: ELAPSED TIME = 34.7 hours; MAN HOURS = 99.1; LABOR COST = $1,066.92.

C. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-33. PATH WHEEL TURNING ANNUAL CONSUMABLE MATERIAL

Description	Cost	Annual Usage/Cost	Remarks
Carbide bits	$11.90 each	40/$476	2 per 15-wheel sets
Oil	1.16/gallon	100/$116	Change once per year
Filters	2.75 each	4/$ 11	1 filter four times/year
TOTAL		$603	For approximately 300 axle sets

Costs reflect 1977 dollars.

No data on electrical power consumption.

TABLE E-34. PATH WHEEL TURNING/CHANGING EQUIPMENT

Manufacturer	Series/Type	Procurement Date/Cost	Function	Remarks
Farrel	(50" wheel lathe)	1974 (used)/187,000 (built 1954)	above floor wheel lathe	trace control; waste buckets on wheels
Niles	Ser. #14493	Approx. 1975 (used)/$-	press wheels	replaced water hydraulic press
Farrel	Ser. #73R2220	Approx. 1973/$100,000 Approx.	bore wheels	—
Stanspec Co.	(2-ton jib crane)	Approx. 1975/$13,486	lift axles set into wheel lathe	—
Whiting	(15-ton crane) (rerated at 7½ ton)	—	lift truck from track to lathe area	also lift one end of car for detrucking

E-7 SOUTHEASTERN PENNSYLVANIA TRANSPORTATION AUTHORITY

System Description

The Southeastern Pennsylvania Transportation Authority (SEPTA) operates buses, trolleys, and subway-elevated lines throughout the city of Philadelphia and into adjacent counties. Only the Market-Frankford and Broad Street heavy-rail rapid transit lines were included in this survey. The Market Street section began in 1905, the Frankford section in 1922, and the Broad Street line in 1928. SEPTA operates 267 revenue vehicles on the Market-Frankford line and 151 revenue vehicles on the Broad Street line (see Table E-35) an average of 36,000 miles per car annually.

The 61.4 miles of revenue track on these two lines consists mostly of 100-pound ASCE rail. The Market-Frankford line has 3,600 feet of 100-pound ARA-B rail. The Broad Street line has approximately 5 miles of 115-pound RE rail and 2 miles of 100-pound ARA-B rail. Track gauge differs between the lines: Broad Street is 4' 8½", Market-Frankford is 5' 2¼".

Seventy percent of the 33.7 miles of revenue track on the Broad Street line is welded rail. All welds are made in the field. All the Broad Street track is in subway. Two miles is of short wood ties bolted to steel channels in concrete; the remainder is of wood half ties in concrete. Five miles of the 27.7 miles of revenue track on the Market-Frankford line is field welded rail. Nine miles of Market-Frankford track is in subway, consisting primarily of wood half ties in concrete. Less than a mile is wood ties bolted to steel channels in concrete. The Market-Frankford line also has 1.4 miles of surface track and 17.3 miles of steel elevated track. These tracks are on wood tie and ballast except for the Frankford section station areas, which are of wood half ties in concrete construction and a small section on the median of I-95, which is direct fixation.

The minimum radius revenue track curves are approximately 135 feet. All guarded curves are manually lubricated. Installation of a pressure-lubricated system is being considered for selected curves.

Resilient Wheels

During the two-year period from 1973 to 1975, SEPTA conducted tests of one revenue service vehicle fitted with Acousta Flex wheels. Boeing Vertol took acoustical measurements to determine the wheel's effect on rail impact and squeal noises. Repeated difficulties were experienced with the resilient material separating from metal. Sixteen different wheels were used on the one test car during this period. At the end of the program, the wheels were trued on SEPTA's underfloor milling machine. No other resilient wheels were tested at SEPTA until this project.

Rail Grinding

Prior to 1970 SEPTA had utilized a self-propelled reciprocating grinding car in its rail maintenance program. In 1970, a SPENO rail grinder train was purchased. Grinding is not performed according to a cyclical schedule; rather, it is performed when judged necessary by track inspection personnel. Basically, grinding is performed as soon as practical on all newly-welded rail; anytime corrugation or batter exceeds 0.010 inches; for spot grinding as prompted by wheel burns; or when indicated by routine and special inspections.

SEPTA's Track Inspection Group inspects all track twice a week. Special attention is paid to sections subject to public or operator complaint. The foreman determines the need for repairs/grinding. Additionally, caliper measurements are made of the entire system's vertical and horizontal rail head wear annually. This detailed annual inspection is documented and used in scheduling future track maintenance. The average rail life at SEPTA is thirty years for tangent track and eight years for curved track.

Typically, 80 miles of track are ground annually at SEPTA during 125 days of grinding. This includes yard track and revenue track sections. It does not necessarily include all 61.4 miles of revenue track. The grinder train operates at 1.5 mph, removing 0.0015 inches of rail surface with each pass. An average of ten passes are made to restore a given section of track.

The grinder train consists of a diesel-powered locomotive, four carts with six grinding stones each, and a 500-gallon water car. The locomotive incorporates a diesel generator, air compressor, and air-conditioned control cab. Each of the grinding stones is aligned to grind the rail at a different angle, so that the original rail contour is restored. The stones are raised and lowered pneumatically, and each has its own electric motor for rotation. A water pump is installed in the last grinder cart, ahead of the water car. The total cost of this train was $250,000 in 1970. A unique feature of this train is the interchangeability of its axle sets to accommodate the differing gauge track on the Broad Street and Market Frankford lines.

The rail grinder is operated only during night revenue service. Single-tracking is required on approximately one-fifth of all revenue track. When single-tracking is not required, four personnel man the train and one Signal Department employee prepares and restores wayside signalling equipment to avoid damage. Revenue headway is not affected. When single-tracking is required, headways are affected and additional Transportation Department personnel must be stationed. Table E-36 lists the rail grinder operation related personnel and hourly wages.

No particular clearance or safety problems are associated with rail grinding at SEPTA. Potential problems with diesel exhaust fumes when grinding subsurface track are controlled by the use of a catalytic converter in the exhaust system. Additionally, the control cab is pressurized and air conditioned.

During subsurface grinding, the water spray tends to minimize dust and contamination of tunnel walls. The laborer assigned to the train is outfitted with a respirator and goggles.

During a typical eight-hour shift, four hours are spent in actual grinding. The other four hours are spent in making ready/securing the train (2 hours), traveling to/from the grinding site (1 hour), and delays for revenue service/switching (1 hour). Table E-37 lists the annual operating and maintenance costs associated with rail grinding at SEPTA.

Wheel Truing

In 1972, SEPTA installed an underfloor wheel milling machine at the Market Frankford line's 60th Street Shop. Prior to that time, the above floor wheel lathe at the Broad Street line's Fern Rock Shop was utilized for both lines. The Fern Rock Shop also employs abrasive brake shoes for minor wheel touch-up.

The 28-inch solid steel wheels on the Market Frankford line average 200,000 to 250,000 miles before condemnation at one-inch tread thickness. These wheels average 60,000 miles between truings. Wheels are inspected whenever complaints are filed and according to schedule. A visual overall car inspection is performed daily on groups of 50 cars. AAR gauge wheel tread and flange measurements are taken on each wheel at 12,000-mile intervals.

The 36-inch solid steel wheels on the Broad Street line average 400,000 to 450,000 miles before condemnation. Wheels are condemned at tape measurements of 160. New wheels tape at 240. These wheels average 100,000 miles between turnings. Wheel inspection on the Broad Street line is also included in daily visual overall car inspections. Scheduled AAR gauge wheel measurements are made at 4,000-mile intervals.

Table E-38 lists the categories and wages of personnel involved in wheel truing and wheel changing at SEPTA. In addition to heavy rail transit cars, the 69th Street Shop also trues wheels for trolleys and maintenance vehicles. Typically, 90 heavy rail transit cars and about 24 trolleys are trued per year without removing trucks or axles from the car. One car set of eight wheels occupies one man for one eight-hour shift. Table E-39 lists the procedures and labor costs associated with this operation. After four cars are trued, an eight-hour shift is spent indexing/replacing carbide inserts, emptying waste chip collection drums, and routine lubrication and filter-type preventive maintenance.

At the Fern Rock Shop, an axle set of two wheels is turned on the above floor lathe in 3.5 hours. Approximately 150 axle sets are trued per year. Table E-39 lists the procedures and manpower expenditures associated with this operation. Ten spare worked trucks are maintained on hand to avoid delaying revenue vehicles requiring truck/axle/wheel repair.

Tables E-40 and E-41 list the procedures and manpower expenditures associated with wheel changing at the 69th Street and Fern Rock Shops respectively.

Table E-42 lists the annual wheel truing consumable component expenditures at SEPTA. In addition to routine preventive maintenance, the manufacturer inspects the underfloor milling machining every 18 months; the above floor lathe receives extensive preventive maintenance checks for one week annually.

Table E-43 and E-44 list the equipment employed in wheel truing and wheel changing at the 69th Street and Fern Rock Shop respectively.

TABLE E-35. SEPTA REVENUE VEHICLES

MANUFACTURER	SERIES	UNLOADED WEIGHT (LBS)	TRUCK TYPE	WHEEL TYPE	CAR PURCHASE DATE/COST	NUMBER OF CARS
BUDD*	601-646	51,170	Adirondack	28" Steel	1959/$ 97,616	45
BUDD*	701-924	46,670	Adirondack	28" Steel	1959/ A-$ 88,756 B-$ 89,013	222
BRILL (North Broad)	1-150	110,580	BRILL 27 MCB	36" Steel	1926/$ 40,910	78
PRESSED STEEL (South Broad)	151-200	106,000	General Steel/ Common Wealth	36" Steel	1938/$ 46,820	50
BRILL (Bridge)	1001-1026	113,800	General Steel/ Common Wealth	36" Steel	1936/$ 52,500	23
BRILL (Norristown Bullet)	200-209	52,290	BRILL 89E2	28" Steel	1931/	7
	203	52,290	BRILL 89E2	28" Steel	1933/	1
BRILL (Strafford)	160-168	63,085	BRILL 27MCB-2X	28" Steel	1924-29/	9
St. Louis (Liberty Liner	Valley Forge	210,000	General Steel/ Common Wealth	31" Steel	1941/$150,000	1

*Market Frankford Line Cars; All other cars operate on Broad Street Line.

TABLE E-36. SEPTA PERSONNEL-RAIL GRINDING

EMPLOYEE	HOURLY WAGE / WITH BENEFITS	TASK
Foreman	$7.56/$10.58	Supervises/coordinates Grinding operation
Track Equipment Operator	7.01/9.81	Operates gringing stones
Track Equipment Motor Person	6.86/9.60	Operates train propulsion unit
Laborer	6.69/9.37	Walks track, supresses fires, general duties
Various Transportation Department Personnel	Varies, averages $550/night	Single-tracking requires towermen, stationmen, signalmen, supervisors
Signal Maintainer (Signal Department)	7.10/9.94	Protects track signal equipment before grinding; restores after grinding

Wages and benefits reflect 1977 dollars.

TABLE E-37. SEPTA RAIL GRINDING COSTS

OPERATIONS			
PERSONNEL	GRINDING NIGHT	ANNUAL COST	REMARKS
4-train personnel	$314.88	$39,360	See Table E-37
Signal Maintainer	78.52	9,940	See Table E-37
Transportation Dept.	550.00	11,000	See Table E-37
CONSUMABLES			
Grinding Stones	$ 31.25	$ 3,906	$12.50ea.; 2.5/night
Fuel Oil	20.48	2,560	$0.45/gal; 45.5 gal./night
Annual Operating Subtotal		$66,766	
MAINTENANCE			
Personnel	-	$12,600	One man 60% of year, maintains and repairs grinder train.
Material	-	$10,650	Various repair/replacement components
Annual Maintenance Subtotal		$23,250	
GAUGE CONVERSION			
Once a year; 3 wks labor		$ 3,400	Mechanical Equipment Repairmen & Helpers, plus haulage costs between Market-Frankford & Broad Street lines
ANNUAL TOTAL RAIL GRINDING COSTS		$93,416	Based on 80 miles ground in 125 eight-hour shifts.

Costs reflect 1977 dollars.

TABLE E-38. SEPTA PERSONNEL-WHEEL TRUING/CHANGING

Employee	Hourly/ With Wage/Benefits	Tasks	Percent of Time Assigned Tasks
Machinist (First Class)	$7.13/$9.98	Operate wheel boring machine and press; true wheels, operate car puller, routine maintenance.	57*
Overhauler	6.68/ 9.60	Disconnect/reconnect trucks; remove/install trucks and axles; adjust brakes.	100
Air Repairman	6.68/ 9.60	Set tripcocks pursuant to brake adjustment after truing	-
Cleaner	6.53/ 9.14	Steam clean axle sets	-

Wages and benefits reflect 1977 dollars.

*Percent for Market-Frankford; all first class machinists rotate through these and other tasks.

TABLE E-39. SEPTA WHEEL TRUING PROCEDURE

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (C)	Remarks
Market Frankford Line - 69th Street Shop							
1.	TRUE WHEELS (axle set of 2 wheels)	2.0	1 machinist	2.0	2.0	$ 19.96	Includes operation of car puller
2.	ADJUST BRAKES	0.5	1 overhauler	0.3	0.3	2.88	Adjust brakes
			1 air repairman	0.2	0.2	1.92	Set tripcocks
	Subtotal	0.5			0.5	$4.80	Per car set
NOTE: Average total truing and handling time/labor costs prorated for one car set of eight wheels: ELAPSED TIME = 8.5 hours; MAN HOURS = 8.5; LABOR COST = $84.64.							
Broad Street Line - Fern Rock Shop							
1.	REMOVE TRUCK	1.0	2 overhaulers	1.0	2.0	19.20	
	Prorated time/labor	0.5			1.0	9.60	For one axle set
2.	REMOVE AXLE	2.0	3 overhaulers	0.25	0.75	7.20	Includes transport of axle
			2 overhaulers	2.0	4.0	38.40	
3.	REMOVE MOTOR	1.0	2 overhaulers	1.0	2.0	19.20	For one axle set
4.	TRUE WHEELS (axle set of 2 wheels)	3.5	1 machinist	1.0	1.0	9.98	Assists with rigging
			1 machinist	3.5	3.5	34.93	Rig and operate lathe
5.	INSTALL MOTOR	1.0	2 overhaulers	1.0	2.0	19.20	
6.	INSTALL AXLE	2.0	see remarks	-	4.75	45.60	Reverse of REMOVE AXLE above
7.	INSTALL TRUCK	1.0	see remarks	-	2.0	19.20	Reverse of REMOVE TRUCK above

NOTES. TABLE E-39
Broad Street Line - Fern Rock Shop

A. Average total truing and handling time/labor costs prorated for one axle set of two wheels:
ELAPSED TIME = 10.5; MAN HOURS = 20; LABOR COST = $193.71.

B. Average total truing and handling time/labor costs prorated for one car set of eight wheels:
ELAPSED TIME = 42 hours; MAN HOURS = 80; LABOR COST = $774.84.

C. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-40. SEPTA WHEEL CHANGING PROCEDURE
(MARKET FRANKFORD LINE -69th STREET SHOP)

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (C)	Remarks
1.	REMOVE TRUCK	1.50	2 overhaulers	1.50	3.0	$ 28.80	
	Prorated time/labor	0.75		0.75	1.50	14.40	For one axle set
2.	REMOVE AXLE	2.50	2 overhaulers	2.50	5.0	48.0	
3.	PRESS OFF WHEELS (axle set of 2 wheels)	0.5	3 machinists	.50	1.50	14.97	Includes handling
	Prorated time/labor	0.25		0.25	0.75	7.49	For one wheel
4.	BORE WHEEL	3.50	1 machinist	3.50	3.50	34.93	Includes handling
	Prorated time/labor	7.0		7.0	7.0	69.86	For one axle set
5.	PRESS ON WHEELS (axle set of 2 wheels)	0.50	See remarks		1.40	14.97	Reverse of PRESS OFF WHEELS above
6.	INSTALL AXLE	2.50	See remarks		5.0	48.0	Reverse of REMOVE AXLE above
7.	INSTALL TRUCK	1.50	See remarks		3.0	28.80	Reverse of REMOVE TRUCK above
	TOTAL	14.5			23.0	$224.60	For one axle set

NOTES:

A. Average total wheel changing time/labor costs prorated for one car; ELAPSED TIME = 58 hours; MAN HOURS = 92; LABOR COST = $898.40.

B. Not included in the above table are costs of reworking axle and journals typically performed at SEPTA whenever wheels are removed. The optimum time achieved in a production line operation for 29 axle sets was 42 man hours per set, including pressing wheels off and on.

C. Laobr cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-41. SEPTA WHEEL CHANGING PROCEDURE (BROAD STREET LINE - FERN ROCK SHOP)

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (C)	Remarks
1.	REMOVE TRUCK	0.5	2 overhaulers		1.0	$ 9.60	Prorated for one axle set
2.	REMOVE AXLE	2.0	2 overhaulers		4.75	45.60	For one axle set
3.	REMOVE MOTOR	1.0	2 overhaulers	1.0	2.0	19.20	For one axle set
4.	CLEAN AXLE	0.4	1 cleaner	0.4	0.4	3.66	Uses steam
5.	PRESS OFF WHEEL	1.0	2 machinists	1.0	2.0	19.96	For one wheel
6.	BORE WHEEL	1.0	1 machinist	1.0	1.0	9.98	For one wheel
7.	PRESS ON WHEEL	1.0	see remarks		2.0	19.96	Reverse of PRESS OFF WHEEL
8.	INSTALL MOTOR	1.0	see remarks		2.0	19.20	Reverse of REMOVE MOTOR above
9.	INSTALL AXLE	2.0	see remarks		4.75	45.60	Reverse of REMOVE AXLE above
10.	REMOVE TRUCK	0.5	see remarks		1.0	9.60	Reverse of REMOVE TRUCK above
	TOTAL	13.4			25.90	$252.26	

NOTES: A. Average total wheel changing time/labor costs prorated for one wheel: ELAPSED TIME = 6.7 hours; MAN HOURS = 12.95; LABOR COST = $126.13.

B. Average total wheel changing time/labor costs prorated for one car: ELAPSED TIME = 53.6 hours; MAN HOURS = 103.8; LABOR COST = $1,009.04.

C. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-42. SEPTA WHEEL TRUING
ANNUAL CONSUMABLE MATERIAL

Market-Frankford Line - 69th Street Shop			
Description	Cost Each	Annual Usage/Cost	Remarks
Carbide inserts			
Bolts Nuts			Bolts & nuts changed each time inserts changed.
Filters			Washable
Other (seals, lube and hydraulic oils, filters, etc.)		-/$500 approx.	
NOTE: No data on electric power consumption.			
Broad Street Line - Fern Rock Shop			
Carbide inserts	$20.00	50/$1,000	4 index positions, 7 locations/wheel
Segmented grind shoes	4.50	900/$4,050	Purchase in lots of 300.

NOTE: No data on electrical power or oil consumption. Costs reflect 1977 dollars.

TABLE E-43. SEPTA WHEEL TRUING/CHANGING EQUIPMENT (MARKET-FRANKFORD LINE - 69th STREET SHOP)

Manufacturer	Series/Model	Procurement Date/Cost	Function	Remarks
STANRAY	Ser. #477	1972/$265,000	Underfloor wheel milling machine	Includes winch-type car puller & vacuum chip waste removal.
CHAMBERSBURG	(300-ton press)	1940/$120,000 (Built in 1920's)	Wheel press	Converted armature press
NILES BEMENT POND	-	1897 Design/$ -	Bore wheels	48" wheel bore
NORM'S-WHEELER	Norlift	1975/$10,000	Rigging press	5-ton jib crane
GLOBE	-	1959/$ -	Lift one or pair of cars for detrucking.	Twin Trolley Hoist
SHAW BOX	(15-ton crane)	1907/$ -	Lift car for detrucking	Requires pit.
ALL STATE ENGINEERING CO.	Ser. #40322	- /$ -	Remove axles from truck	5-ton jib crane
HOMEMADE	(Transfer table)	1907/$ -	Move trucks, axles or forklifts across shop	-
VARIOUS	(2½-ton forklift)	- /$ -	Move wheels to/from storage, axles between hoists and press/bore.	-

TABLE E-44. SEPTA WHEEL TRUING/CHANGING EQUIPMENT (BROAD STREET LINE - FERN ROCK SHOP)

Manufacturer	Series/Model	Procurement Date/Cost	Function	Remarks
BALDWIN-LIMA-HAMILTON	Ser. #23655 Model WL52H	1952/$450,000	Above-floor wheel lathe.	Template, disposable inserts, lifting beam.
FARRELL-BETTS	-	1935/$150,000	Bore wheels.	-
CHAMBERSBURG	-	1935/$120,000	Wheel press.	Two presses: 600-ton & 200-ton
BOX	(20-ton crane)	-/$ -	Lift cars for de-trucking.	-
BOX	(15-ton crane)	-/$ -	Removing axles from truck.	-
BOX	(5-ton crane)	-/$ -	Transporting axle sets & wheels near presses & boring machine.	-
VARIOUS	(3-ton fork-lift)	-/$ -	Move wheels to/from storage, axles between hoists & press/bore	-
-	Wheel cart	-/$ -	Transport single wheel in vicinity of bore.	-
BOX	(Transfer Table)	-/$ -	Move trucks, axles, 75-ton or forklifts across shop.	-

E-8 WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

System Description

The Washington Metropolitan Area Transit Authority (WMATA) operates bus and rail services in the Washington, D.C. and surrounding Virginia and Maryland suburban areas. Heavy rail service was inaugurated in March 1976. At the time of this survey, April 1977, some 5.2 of the planned 99.7 miles of revenue track had been put in service. Some 40 of the projected 476 revenue vehicles had been received. Table E-45 lists revenue vehicle data. Upon completion of the 100-mile system, each car is expected to average 75,000 miles per year.

All track consists of 115-pound welded RE rail utilizing direct fixation construction in subway and aerial structure and wood tie and ballast construction on surface sections. In the subway floating slab construction is employed in areas sensitive to ground born vibration. Planned are 48.3 route-miles of subsurface track, 42 miles of surface track, and 9.5 miles of elevated track. Track gauge is 4'8½".

Sound barrier walls are employed on aerial structures in selected residential areas. Acoustical spray treatment of tunnel walls was abandoned due to application, maintenance, and cost problems. The use of rail lubricators on curved track is not planned as the minimum radius of curvature on main line track is 700 feet.

The floating slab installation in tunnels is expected to result in a 10dBA reduction in noise in nearby buildings compared to non-floating slab construction in the same system. Specifications for revenue vehicles require the following maximum noise levels at 70 70 mph on wood tie and ballast track: 84dBA, 100 feet from an

eight-car train or 50 feet from a two-car train; 82 dBA, 100 feet from a four-car train; 80 dBA, 100 feet from a two-car train.

Resilient and Ring Damped Wheels

WMATA has no experience with resilient or ring damped wheels.

Rail Grinding

Rail grinding will be an integral part of WMATA's rail maintenance program. The purpose for grinding rail is to enhance patron comfort by reducing noise and vibration, and to minimize equipment wear. The purchase of a rail grinding train is planned. Though the manufacturer/unit has not been chosen, the cost is anticipated to be approximately $850,000.

It is projected that grinding of all revenue track will be accomplished on an annual basis. The grinder train will remove approximately 0.005 of rail surface with each pass, traveling at approximately two miles per hour.

Among the grinder trains under consideration are those manufactured by Mannix and by Fairmont. Both units would satisfy the above requirements, are approximately 100 feet long, would satisfy an 11-foot vertical clearance restraint, incorporate a water tank of approximately 8,000 gallons capacity, and limit wheel loading to 15,000 pounds as required by aerial structure restrictions. A basic difference in these diesel propelled units is the number of grinding stones employed. The Mannix unit employs a total of 24 grinding stones, whereas the Fairmont unit employs a total of 40 grinding stones distributed among five grinding carts.

It is anticipated that the grinder train will require three full-time operating personnel: a track supervisor and two track equipment operators. It is expected that seven hours out of an eight-hour shift could be spent in actual grinding. Grinding is projected to be accomplished during both revenue and non-revenue hours. The track section to be ground will be taken out of service, but due to the flexibility of WMATA's switching arrangement, revenue service will be uninterrupted.

Wheel Truing

Presently all wheel truing is accomplished at WMATA's Brentwood Shop on an underfloor lathe. During the first year of operation, approximately 156 axle sets were trued. Eventually, one or two additional truing machines will be installed at storage and inspection facilities.

Wheels are inspected monthly utilizing an AAR gauge. Eventually it is anticipated that this inspection will be scheduled approximately every 10,000 miles or every six weeks. Wheel life of 300,000 miles is projected for the completed system.

Due to the Brentwood Shop layout, a car may not be driven over the underfloor lathe. Consequently, trucks are removed from the car whenever wheels are to be trued. An average of six axle sets of two wheels are trued in an eight-hour shift. Wheels are trued to within 0.005 inches concentricity.

Table E-46 lists the categories and hourly wages of personnel associated with wheel truing and changing.

Table E-47 lists the manpower expenditure associated with wheel truing.

Table E-48 lists the procedures and manpower expenditures associated with wheel changing.

Table E-49 lists the equipment installed at the Brentwood Shop employed in wheel truing and wheel changing.

Table E-50 lists the wheel truing consumable component expenditures.

TABLE E-46. WMATA REVENUE VEHICLES

Manufacturer	Series	Unloaded Weight (lbs)	Truck Type	Wheel Type	Car Purchase Date/Cost	Number of cars
Rohr	"WMATA"	72,000	Rockwell HPD-4	28"steel	1972/$297,000	40 (C)

Notes: A. All motors are self-ventilated with internal fans.

B. Brakes: dynamic brakes down to approximately 15 mph, then disc brakes.

C. As of April 1977. A fleet of 476 vehicles is planned.

TABLE E.47. WMATA PERSONNEL - WHEEL TRUING/CHANGING

Employee	Hourly/ with Wage/Benefits	Tasks	Percent of Time Assigned Tasks
Machinist	$8.24/$10.71	Operate underfloor lathe; press and bore wheels	*
Mechanic	8.24/ 10.71	Remove trucks/axles, connec/disconnect truck	*

* Machinists now operate lathe only one-half day per week; eventually, it will be a full-time job.

Costs reflect 1977 dollars.

TABLE E-48. WMATA TRUING PROCEDURE

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost (C)	Remarks
1.	REMOVE TRUCK	1	1 mechanic	1	1	$10.71	includes set-up
2.	TRUE WHEELS (axle set of 2 wheels)	1.33	2 machinists	1.33	2.67	28.60	includes handling
3.	INSTALL TRUCK	1	1 mechanic	1	1	10.71	--

Notes:
A. Average total truing and handling time/labor costs pro-rated for one axle set of 2 wheels:
ELAPSED TIME = 2.33 hours; MAN-HOURS = 3.67; LABOR COST = $39.91
B. Average total truing and handling time/labor costs pro-rated for one car set of 8 wheels:
ELAPSED TIME = 9.33 hours; MAN-HOURS = 14.67; LABOR COST = $157.24.
C. Labor cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-49. WMATA WHEEL CHANGING

Step	Operation	Elapsed Time (hr)	Personnel	Time (hr)	Man-Hours	Labor Cost(B)	Remarks
1.	REMOVE TRUCK	.5	1 mechanic	.5	.5	$ 5.36	Prorated for one axle set
2.	REMOVE AXLE	2.5	2 mechanics	2.5	5.0	53.55	--
3.	PRESS OFF WHEEL	.5	2 machinists	.5	1.0	10.71	Includes handling
	Prorated time/labor	1.0		1.0	2.0	21.42	For one axle set
4.	BORE WHEEL	.33	1 machinist	.33	.33	3.54	Includes handling
	Prorated time/labor	.67			.67	7.18	For one axle set
5.	PRESS ON WHEEL	1.0	2 machinists	1.0	2.0	21.42	For one axle set
6.	INSTALL AXLE	2.5	see remarks		5.0	53.55	Reverse of REMOVE AXLE above
7.	INSTALL TRUCK	.5	see remarks		.5	5.36	Reverse of REMOVE TRUCK above
	Total	8.67			15.67	$167.84	For one axle set

Notes: A. Average total wheel changing time/labor costs prorated for one car:

ELAPSED TIME = 34.69 hours; MAN-HOURS = 62.68; LABOR COST = $671.36.

B. Labor Cost includes hourly wage with benefits and reflect 1977 dollars.

TABLE E-50. WMATA WHEEL TRUING/CHANGING EQUIPMENT BRENTWOOD SHOP

Manufacturer	Series/Type	Procurement Date/Cost	Function	Remarks
HEGENSCHEIDT	104	1972/$226,000	underfloor wheel lathe	Truck removed from car due to shop layout; conveyor chip removal system; cost includes installation, excludes construction of pit.
HEGENSCHEIDT	VTL Model RQ	1973/$209,000	bore wheels	Cost includes installation.
FARREL	--	1974/$187,000	press wheels	Cost includes installation.
VARIOUS	(2, 10, 15 ton cranes)	various	handling axes and trucks	Cranes used depends on other activities.
WHITING	(2 hoist systems including screw jacks)	--/$--	lifting cars, lifting trucks	Can lift married car pair simultaneously, then lower trucks independently.
--	(transfer table)	--/$--	move axle set to lathe track	Rotates from staging/storage track to track feeding lathe.

TABLE E.51. WMATA WHEEL TRUING ANNUAL CONSUMABLE MATERIAL

Description	Cost (each)	Annual Usage/Cost	Remarks
Carbide inserts	$5.00*	System incomplete	1 insert used/12 wheels; 4 cutting edges each each insert.

*1977 dollars

E.9 SAN FRANCISCO BAY AREA RAPID TRANSIT DISTRICT

System Description

The Bay Area Rapid Transit District (BART) was formed in 1957. Limited revenue service began in 1972 on 28 miles of track. Service was expanded to 71 miles (full system) in 1974. BART operates 450 vehicles (Table E-52).

Rail sections are continuously welded on direct fixation fasteners in subway and aerial structure and on predominately concrete ties in surface areas. The system consists of approximately 19 miles of subway and tunnel, 23 miles aerial, and 25 miles surface. The Trans-Bay Tube accounts for four miles. Track gauge is 5 ft. 6 in.

Resilient Wheels

One car set each of Bochum and Acoustaflex wheels were installed in 1972. The Bochum wheels were removed in 1977 because the external current shunts had been broken by interference with frogs and switches. The wheels ran for approximately 200,000 miles. The Acoustaflex wheels will be removed in the near future because of the same problem. They will have logged nearly 300,000 miles.

The external shunts were not part of the original design for either wheel. The shunts were added at BART to accommodate return currents.

The acoustical performance of these wheels, as well as the standard wheel, is documented in a report by Wilson, Ihrig & Associates, dated June 21, 1972.

Rail Grinding

Rail grinding is presently accomplished on a 134-day schedule. A Speno machine using 24 stones is utilized. This schedule was developed through operating experience and is

based on the degree of corrugation that occurs over a specific period. Corrugation is most severe in the area of short radius curves.

Tables E-53, E-54 , and E-55 list the equipment, personnel, and consumable materials used in the rail grinding process.

<u>Wheel Truing</u>

During 1977 approximately 1,800 wheels were trued at the BART Hayward shop. Wheels are not trued as part of a noise control program, but rather to remove flat spots which occur mainly due to slip/spin control problems.

Wheels are trued while on the vehicle or on individual axle sets.

Wheel truing, as a result of flat spots, is expected to drop sharply in 1978. However, the numbers will gradually increase as wheels are cut to restore flange contours.

Tables E-56, E-57, and E-58 list the personnel, procedure, and equipment used in wheel truing and changing.

TABLE E-52. BART REVENUE VEHICLES

Manufacturer	Series/Type	Unloaded Weight (lbs)	Truck Type	Wheel Type	Car Purchase Date/Cost	No. of Cars
ROHR	A	62,000	2 axle Motor-Driven	Aluminum Center 30"	1967/$1,125,000*	4
ROHR	A	62,000	"		1969-72/$290,000	146
ROHR	A	62,000	"	"	1973-74/$384,000**	26
ROHR	B	60,000	"	"	1967/$1,025,000*	6
ROHR	B	60,000	"	"	1969-72/$210,000	94
ROHR	B	60,000	"	"	1972/$358,000	100
ROHR	B	60,000	"	"	1973-74/$364,000	74
					TOTAL	450

*Test models; converted to revenue service configuration

**Less on-board ATO and communications equipment

TABLE E-53. BART RAIL GRINDING EQUIPMENT

Manufacturer	Series Name/No.	Procurement Date/Cost	Function
SPENO	Rail Grinding Train	1972	Grind Main-Line Rail

TABLE E-54. BART RAIL GRINDING PERSONNEL

Employee	Hourly Wage	With Benefits	Task	Percent of Time Assigned Task
Sr. Equipment Oper.	$9.67/	-	Operate Locomotive	30
Sr. Equipment Oper.	$9.67/	-	Operate Rail Grinding Train	30
Equip. Operator	$8.78/	-	Assist with Train Operations	30
Equip. Operator	$8.78/	-	Assist with Train Operations	30

TABLE E-55. BART RAIL GRINDING CONSUMABLE MATERIALS

Description	Cost	Remarks
Grinding Stones	500 per year @ $18 ea.	18-hour average life
10 gallons fuel per hour	$0.50 per gallon	
Miscellaneous repair parts	$1,500 per year	
Miscellaneous fuel--oil--filters	$500 per year	

TABLE E-56. BART PERSONNEL, WHEEL TRUING/CHANGING

Employee	Hourly Wage	With Benefits	Task	Percent of Time Assigned Task
Transit Vehicle Mechanic III	$9.67/	-	Operate Wheel Truing and Wheel Pressing Machinery	40

TABLE E-57. BART WHEEL CHANGING PROCEDURE

Step	Operation	Elapsed Time (hr)	Personnel	Man-Hours	Labor Cost	Remarks
1.	REMOVE TRUCK	0.25	2	0.50	$ 4.83	All values prorated for one axle
2.	REMOVE AXLE (A)	1.0	2	2.0	19.34	Complete truck disassembly
3.	PRESS OFF WHEEL (B)	1.0	2	2.0	19.34	
4.	BORE WHEEL (C)	0	0	0	0	
5.	PRESS ON WHEEL	1.0	2	2.0	19.34	
6.	INSTALL AXLE	1.0	2	2.0	19.34	
7.	INSTALL TRUCK	0.25	2	0.50	4.83	
	TOTAL	4.50		9.00	$87.02	

NOTES: A. Axle assembly (Assembly consists of wheels, in-board bearings, friction discs, drive gear ass'y).

B. With hydraulic assist (No axle or wheelscoring - wheels delivered with correct bore).

C. BART not equipped to bore wheels.

D. Labor costs reflect 1977 dollars but do not include benefits.

E. Average total wheel changing time/labor costs prorated for one car:
ELASPED TIME = 18 hours; MAN-HOURS = 36; LABOR COST = $348.08.

TABLE E-58. BART WHEEL TRUING EQUIPMENT

Manufacturer	Series/Type	Procurement Date/Cost	Function	Remarks
FARREL (HEGENSCHEID LICENSE)	Underfloor Lathe	1970/$250,000	Wheel Truing	

APPENDIX F

TABULATION OF A-WEIGHTED SOUND LEVEL DATA FOR TEST PHASES I, II, AND III*

*Notch filter used on all tests except TURN and STATION-STOP tests. Interim levels are the average of the two in-car microphones: one at car center and one over the truck.

SUMMARY OF TEST RESULTS - A-WEIGHTED SOUND LEVEL - dBA

TANGENT WELDED TRACK - TW

Train	Direction	Control Track			Test Track		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE 1A (unground rail on all track sections)							
Worn Stnd.	W	70	85.8	83.8	78	87.5	84.2
	E	58	81	80.9	56	83.5	78.2
	E	56	80.5	79.4	62	82.5	79.9
	W	42	75.5	74.6	41	77	74.5
	E	40	75.2	75.9	42	77.8	73.6
	W	70	84.8	81.5	78	87	83.2
New Stnd.	E	62	79.2	75.8	62	82.8	75.2
	W	75	82.2	76.6	81	86.5	79
	E	67	80.8	76	60	82.8	75.4
	W	76	82.5	77.4	82	86.5	79.2
	E	40	73.5	70.6	46	77	73.6
	W	40	74	68.9	41	77	69.6
	E	58	--	74.5	56	80.5	75.1
	W	68	81	75.4	74	84.5	77.4
PHASE 1B (rail ground test section only)							
Worn Stnd.	E	59	85	77.5	60	84.2	77.5
	W	74	86.8	79.2	80	88.5	80.5
	E	60	83	77	62	83.5	77.1
	W	76	87.2	79.6	79	88.2	79.8
	E	37	77.5	69.9	39	79	72.9
	W	41	78.2	71.2	40	77.8	71.0
	E	60	84	76.8	62	84.2	76.9
	W	45	78.8	73.0	42	78.8	72.5
	E	62	84.5	76.2	60	83.2	76.1

TANGENT WELDED TRACK - TW [CONTINUED]

Train	Direction	Control Track			Test Track		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IB [cont'd]							
New Stnd.	W	70	83.2	76.4	74	--	77.4
	E	59	80.8	71.6	58	80.2	71.6
	W	66	81.8	74.8	70	84	76.6
	E	59	--	72.4	59	80.5	72.2
	W	72	83.2	75.2	75	85.2	76.2
	E	42	76	68.5	41	78	68.1
	W	43	76.5	69.2	42	78	70.2
	E	59	80.8	73.2	59	80.8	73.0
	W	72	83.5	75.2	75	85	76.9
PHASE IC (New standard wheels were trued)							
Worn Stnd.*	W	44	78.8	74.1	46	79.5	74.4
	E	39	77.2	75.4	48	80.2	76.9
	W	46	80.2	76.5	44	80.2	75.5
	E	57	82.0	78.1	60	86	79.9
	E	68	84.5	81.5	66	87	80.8
	W	60	83.5	80.1	59	85.2	79.4
	E	69	84.2	82.2	66	87.2	81.6
	W	76	88.0	82.8	80	90.5	84.9
	*Tests run with single car.						
New/Trued Stnd.	W	42	77.2	73.5	39	77	71.5
	E	37	76.2	70.9	40	--	72.5
	W	63	84.2	76.5	58	83.2	75.8
	E	56	83	76.4	59	84.2	76.5
	W	80	89.5	81	70	87.5	79.1

TANGENT WELDED TRACK - TW [CONTINUED]

Train	Direction	Control Track			Test Track		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IC [cont'd]							
New/Trued Stnd.	E	67	85.2	79.2	64	86	78.1
	W	80	89	80.9	81	--	81.1
	E	64	84.5	77.9	56	84.2	76.8
PHASE IIA (resilient wheels tested for first time)							
New/Trued Stnd.	E	41	76.8	74.1	40	76	75
	W	79	87.8	80.4	82	86.8	82
	E	61	84.2	78	61	83	77.4
	W	77	87.5	80.1	79	86	81.4
	E	67	85.8	79.1	61	82.8	77.2
	W	42	77.5	71.6	42	76	70.9
Acousta Flex	E	56	81.8	75.2	54	80	75.6
	W	67	85.8	77	67	83.2	77.1
	E	57	82.8	76.2	56	79.8	76.9
	W	67	85.8	77	67	84.5	77.6
	E	39	--	71.9	39	75.2	71.9
	W	43	78.5	72.9	43	76.8	71.8
Penn Bochum	E	40	76.5	68.1	42	77.2	70.8
	W	70	87	78.8	69	85	78
	E	61	84.8	76.8	60	82	76.2
	W	71	87.8	79.4	70	85.5	78.8
	E	57	83.5	75.8	60	83.5	76.5
	W	44	78	73	43	76.2	72.9

TANGENT WELDED TRACK - TW [CONTINUED]

Train	Direction	Control Track			Test Track		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IIA [cont'd]							
SAB	E	59	82.8	75.8	59	81.5	76.1
	W	74	85.8	78.4	76	85.5	78.7
	E	59	82.2	75.1	59	82.2	76.6
	W	75	87.2	78.9	81	86.5	79.5
	E	43	76	72	41	73.8	70.6
	W	42	76.2	70	41	74.5	69.6
PHASE III (tests performed after a 9-months wear period)							
Worn Stnd.	W	44	78.5	73.2	44	78.8	73.4
	W	56	81	75.1	54	80.2	75.1
	W	79	89	81.4	79	88.5	82.5
	W	44	79	73.4	44	79	73.4
	W	73	88.8	81	72	87.2	81.8
New/Trued Stnd. [Run as 3-car train with a Bochum wheel]	W	48	79.8	74.2	48	79	74.4
	W	68	86.5	79	54	81.2	76.2
	W	77	--	80.8	79	88	82.1
Acousta Flex/ Penn Bochum	W	48	--	72.9	46	--	71.6
	W	65	85.5	76.9	61	84.8	75.2
	W	80	88.2	80	82	88.2	80.1
	W	41	78.8	71.9	42	79	73.1
	W	62	83.5	77.2	63	84	76.5
	W	82	89	80.8	77	87.5	80.5
SAB	W	43	79.8	72.9	40	78.5	72.5
	W	69	88.5	78.1	70	86.8	79.5
	W	72	88.8	80.5	70	87.2	78.8

SUMMARY OF TEST RESULTS - A-WEIGHTED SOUND LEVEL - dBA

TANGENT JOINTED TRACK - TJ

Train	Direction	Control Track			Test Track A			Test Track B		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE 1A (underground rail, old joint bars)										
Worn Stnd.	W	63	89.5	--	68	89.8	--	70	90.8	--
	W	58	89.2	82.6	60	88.5	82.0	60	90	83.3
	E	80	93.9	86.4	76	91.8	85.0	74	93.5	86.8
	W	60	89.5	82.9	58	89.2	82.8	60	89.5	82.9
	E	80	--	86.9	78	--	85.5	76	--	86.9
	W	40	84.2	77.8	40	83.5	77.8	40	84	78.2
	E	37	84.8	77.4	40	84	77.0	38	84.2	77.8
	W	60	89.2	83.3	60	89	82.6	59	89	83.5
New Stnd.	E	84	94	83.1	82	91	82.6	78	92.5	84.1
	W	60	88	78.1	60	86.5	77.9	58	86.8	77.0
	E	86	93.5	83.3	83	91.8	82.0	82	93.2	84.1
	W	60	87.2	77.5	61	86.8	79	60	87	78.0
	E	40	85	75.4	41	82.2	74.5	40	84.2	74.5
	W	42	83.2	74.0	40	83	73.4	41	83.2	74.2
	E	59	89	78.5	59	87.8	78.1	57	89.2	80.4
	W	58	--	78	60	--	78.4	60	--	77.2

TANGENT JOINTED TRACK - TJ [CONTINUED]

Train	Direction	Control Track			Test Track A			Test Track B		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE 1B (new joint bars on Test Track B)										
Worn Stnd.	E	48	87.5	--	75	94	83.8	74	94.2	84.8
	W	58	88.2	79.8	56	89.2	79.2	59	88.5	81.0
	E	80	93.8	84.2	79	93.8	84.6	76	94.2	85.1
	W	60	--	79.5	59	88.5	79.9	59	89	80.9
	E	42	84.8	76.4	41	84.5	75.5	39	84.5	76.5
	W	41	84.2	75.5	41	84	74.8	41	84.8	76.6
	E	80	93.2	84.4	78	93.5	84.5	75	95	85
	W	41	83.8	75.8	41	83.5	75.6	41	85.8	77.0
	E	59	88.5	81.2	60	89.2	81.0	60	91.2	82.0
New Stnd.	W	62	86	78.5	59	87	77.4	56	87.2	79.8
	E	72	89.5	79.9	70	90.8	79.5	70	91.8	81.8
	W	59	85.8	77.0	62	87.2	77.5	64	88.2	79.4
	E	74	89.2	79.5	71	90.8	79.8	70	92.2	80.8
	W	62	86	77.6	64	88	77.4	62	88.2	78.9
	E	41	81.8	73.0	46	85.5	74.5	39	84	74.6
	W	39	81	72.6	41	82.2	72.8	39	81.8	73.1
	E	74	90	81.1	72	91	80.0	71	92.5	81.5
	W	62	86.5	78.0	59	87.2	76.5	62	87.2	78.4

TANGENT JOINTED TRACK - TJ [CONTINUED]

Train	Direction	Control Track			Test Track A			Test Track B		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IIA (resilient wheels tested for first time)										
Worn Stnd.	E	62	89.2	84.5	60	89.2	83.9	60	89.5	84.1
	W	39	83.2	78.5	37	82.5	83.7	43	84.8	84.6
Trued Stnd.	E	42	82.8	76.2	41	83.8	76.2	41	83	77.4
	W	57	86.2	79.6	58	87.8	78.5	65	88.5	81.5
	E	82	92.8	84.1	79	93.8	83.9	77	94	85.4
	W	59	86.8	79.5	59	87.5	79.2	57	86.5	79.7
	E	75	94.5	83.1	81	94.2	83.9	80	94.8	85.9
	W	41	83.0	75.6	39	82.2	74.2	40	82.2	75.2
Acousta Flex	E	61	85.5	80.4	62	88.2	80	65	89	82.4
	W	61	86	79.5	55	86.5	78.8	57	86.2	79.6
	E	53	83.5	79	57	86.8	78.9	63	88.5	82.8
	W	60	85.5	80.8	63	88	80.4	59	86.5	80.8
	E	41	80	77	41	83.2	75.2	41	83	76.4
	W	40	80.5	76.6	40	82	74.2	40	81.5	75.9
Penn Bochum	E	38	80.5	72.4	40	82.5	74	41	83.5	74.5
	W	61	86.5	79.5	65	89	81	67	88.5	81.2
	E	65	88	80.4	65	91.2	81.1	67	90	83

TANGENT JOINTED TRACK - TJ [CONTINUED]

Train	Direction	Control Track			Test Track A			Test Track B		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IIA [cont'd]										
Penn Bochum	W	63	87.2	79.6	59	87.5	79.9	62	86.5	80.8
	E	65	88	80.8	67	90.5	81.1	68	90.5	82.2
	W	41	81.5	76.2	41	82.7	75.4	40	82.0	76.6
SAB	E	66	88.2	83.4	77	94	83.6	75	93.2	84.8
	W	67	90	82	71	91	82	73	90.8	83.9
	E	81	92.5	84.2	78	94	84.1	76	93.2	84.2
	W	57	86.5	79.2	59	88	80.5	59	88	81.2
	E	41	81.2	77.2	41	83	74.5	40	83	74.9
	W	43	82.2	76	42	83	75.4	41	82.2	75.9
PHASE IIB (rail ground on Test Tracks A and B)										
Worn Stnd.	E	74	90.5	83.8	78	92	84.2	78	94.5	86.1
	W	68	89.5	81.8	60	88	80.6	64	89.5	81.9
	E	77	92	84.6	76	92.2	84.2	77	94.2	86.1
	W	40	81.8	74.6	40	82	74.9	40	83.2	76.9
	E	44	83.2	76.9	44	83.5	75.9	45	85.5	78.5
	W	67	89.8	81.2	67	90	81.8	61	88.2	82.1

TANGENT JOINTED TRACK - TJ [CONTINUED]

Train	Direction	Control Track			Test Track A			Test Track B		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IIB [cont'd]										
Trued Stnd.	E	82	90.2	84.5	80	90.2	83.6	79	93.8	85
	W	60	85.2	79.4	60	85	79.9	60	88.2	80.6
	E	83	90.2	84.1	82	91.2	83.5	80	94	85.6
	W	42	80.2	75.6	42	79.8	74.5	42	82.2	77
	E	46	81.5	76.9	51	83.5	77.9	42	84	77
	W	60	86.2	80.1	60	85	79.5	62	87.5	81.5
Acousta Flex	E	74	87.8	79.5	69	86.5	81.8	64	88.8	83.2
	W	62	83.8	78.5	64	85.2	80.9	66	88.0	82.1
	E	80	86.2	80.9	74	87	81.6	67	89.8	84.1
	W	46	79.5	74.2	46	80.2	74.8	57	85	79.9
	E	48	81.5	76.2	46	81	76.5	46	84	78.1
	W	63	84	78.5	64	86	80.6	65	87.5	83
Penn Bochum	E	62	83.2	79.9	61	85	80.2	60	87.2	81.0
	W	60	82.8	77.8	64	84.8	81.1	59	85.5	81.1
	E	58	82.5	78.2	54	83.5	78.2	59	87	81.1
	W	44	78.5	74.1	42	79.2	74.4	42	81.8	77.2
	E	42	77.8	74.8	46	81.8	74.9	46	84.5	78.2
	W	72	85	80.8	74	86.8	81.6	74	88.2	83.2

TANGENT JOINTED TRACK - TJ [CONTINUED]

Train	Direction	Control Track			Test Track A			Test Track B		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IIB [cont'd]										
SAB	E	83	89.2	83.8	80	88.8	83.1	78	92.8	85.2
	W	64	85.2	79.2	62	85.2	79.6	62	88	81.9
	E	83	89.2	83	81	90.2	83.5	78	92.8	85.2
	W	42	79.2	74.8	60	84.8	78.8	67	89	83.1
	E	45	80.2	75.8	43	80.8	74.9	42	84.2	76.2
	W	62	85.2	79.6	63	85.8	80.4	63	88.2	82.4
	E	74	86.8	82.5	65	86.5	80	54	88.5	80.4
	W	43	79.8	74.5	43	--	74.5	42	82.8	77.9
PHASE III (tests performed after a nine-months wear period)										
Worn Stnd.	W	43	--	74.5	42	--	75.1	42	--	77.4
	W	58	--	79.5	54	--	78.1	48	--	79.8
	W	80	--	84.4	82	--	83.9	80	--	85.5
	W	44	--	76.9	42	--	75	42	--	77.6
	W	67	--	82	61	--	80.5	61	--	81.9
New Stnd.	W	45	--	76.8	44	--	76	44	--	78
	W	59	--	79.4	61	--	79.2	64	--	81.8
	W	80	--	82.4	82	--	82.4	84	--	84.2

TANGENT JOINTED TRACK - TJ [CONTINUED]

Speed	Direction	Control Track			Test Track A			Test Track B		
		Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE III [cont'd]										
Acousta Flex/ Penn Bochum	W	42	--	73.9	42	--	74	44	--	76.5
	W	66	--	80.2	64	--	79.5	65	--	82.5
	W	78	--	81.6	80	--	81.6	82	--	84.6
	W	43	--	75. 1	42	--	74.2	42	--	76.2
	W	64	--	79.5	63	--	78.6	63	--	81.1
	W	70	--	80.8	73	--	81.2	73	--	83.9
SAB	W	43	--	75.2	42	--	74.6	44	--	76.5
	W	66	--	80.8	66	--	80.4	64	--	81.8
	W	72	--	82.1	72	--	81.2	72	--	83.4

SUMMARY OF TEST RESULTS - A-WEIGHTED SOUND LEVEL - dBA .

FROG TEST TRACK - FROG

Train	Direction	Speed km/hr	Wayside dBA	Interior dBA
Worn Stnd.	E	64	92.8	82.8
	W	82	97.2	83.9
	E	64	93.5	83.4
	W	80	96.5	83.4
	E	41	88.0	79.5
	W	42	87.2	77.0
New/Trued Stnd.	E	66	93.0	83.5
	W	83	94.0	--
	E	67	93.5	83.0
	W	84	96.0	84.0
	E	41	87.5	78.1
	W	44	85.5	76.9
Acousta Flex	E	56	90.0	82.1
	W	59	89.8	80.8
	E	59	90.2	82.8
	W	60	89.2	80.8
	E	39	86.8	78.9
	W	44	86.0	77.9
Penn Bochum	E	51	89.0	81.1
	W	73	92.8	86.2
	E	52	88.5	81.0
	W	73	93.0	84.1
	E	32	83.2	76.6
	W	44	86.0	77.8

FROG TEST TRACK - FROG (CONTINUED)

Train	Direction	Speed km/hr	Wayside dBA	Interior dBA
SAB	E	60	91.0	81.6
	W	84	94.5	83.5
	E	66	92.2	83.1
	W	84	95.0	83.9
	E	42	87.2	77.6
	W	44	86.2	77.1
	E	66	92.2	82.8
	W	43	85.2	--

SUMMARY OF TEST RESULTS - A-WEIGHTED SOUND LEVEL - dBA

CURVE TEST TRACK - TURN

Train	Control Track			Test Track		
	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IA (unground rail on all test sections)						
Worn Stnd.	18	91.2	76.8	21	88.8	80.2
	18	90.5	--	21	89.2	--
	18	91.2	--	20	91.2	--
	17	89.5	77.5	20	90.5	81.5
	18	88	78	21	91	81.5
	18	91.5	76.8	21	90.2	81.2
	15	92	--	20	92	--
	15	91.8	77.5	22	91	81.2
	15	91	77.2	23	92	81
New Stnd.	16	86	73	19	86.2	71.8
	16	--	74.5	19	--	77
	22	87.5	75.8	24	88.5	80
	20	85	74.2	20	84.8	74.2
	16	83.5	--	19	85	--
	19	86.8	75.0	21	84.5	73.5
	19	87.8	76.2	22	84.2	73.8
PHASE IB (rail ground on both control and test sections)						
Worn Stnd.	23	92	76.2	26	95.5	79.9
	22	93	76.5	30	93	79.4
	23	91.8	76.1	22	89.8	76.8
	19	93	76.9	22	90.8	77.2
	24	95.5	74.8	26	93.2	77.8
	18	94.2	77.4	24	94.2	78.1

CURVE TEST TRACK - TURN [CONTINUED]

Train	Control Track			Test Track		
	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IB [cont'd]						
New Stnd.	22	90.8	74	20	90	74.9
	22	90	73.5	22	91	76.6
	20	90	74.4	22	89.5	77.5
	18	82	75	21	86	76.4
	20	87.5	74.8	20	86	76.2
	18	88	74.8	20	88	76.9
PHASE IC (new wheels were trued)						
Worn Stnd.	23	94.8	75.6	20	93	80.2
	23	95	83.5	20	93.5	79.6
	22	95	74.4	19	92	77.5
	22	89.8	76.4	21	89	86.5
	24	87.8	74.8	23	88.5	84.5
	23	88.2	83.8	21	89	88.2
New/Trued Stnd.	22	89.2	74.5	20	96	81.5
	24	90	72.8	21	96.8	81.8
	20	91	75.6	22	92.8	77.6
	22	87.2	73.5	21	89.2	76.4
	22	87.2	79	23	89.5	79.4
	24	90.5	81	25	90.2	84.5
PHASE IIA (resilient wheels tested for first time)						
New/Trued Stnd.	18	86.2	75.1	24	78.2	71.2
[wet track]	20	86.2 2	75	24	77.5	71.8
	20	86	71.2	26	78	71.9

CURVE TEST TRACK - TURN [CONTINUED]

Train	Control Track			Test Track		
	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE IIA [cont'd]						
Acousta Flex	16	75.8	74.8	19	76	72.8
	14	--	72.8	20	--	73.8
	15	79	76.6	15	78	74.1
	14	82.2	74.6	20	77.2	76.6
	15	79.8	75.4	20	79.2	76
	20	85.2	77.9	21	77.2	75.5
Penn Bochum	26	77.5	77.9	26	79	74.9
	23	83.5	76.9	24	82.2	73.9
	15	82.5	76	18	78	71
	16	--	72.9	19	--	71.1
	16	77	71.4	21	77.2	71.1
	15	75.2	71	22	79.5	71.2
SAB	16	83.5	76.5	20	80.2	73.2
	16	86.2	76.6	21	88.8	79
	16	89	78.1	20	93	80.1
	22	83.8	78.5	19	76.8	81.6
	17	85.5	78.6	20	87.0	82
	17	84	78.1	24	91.0	82.4
PHASE III (tests performed after a nine-months wear period)						
Worn Stnd.	19	90.2	77	23	88.5	75.5
	23	92	74.6	24	93.2	80.4
	20	89.8	76.4	20	89	74.6

CURVE TEST TRACK - TURN (CONTINUED)

Train	Control Track			Test Track		
	Speed km/hr	Wayside dBA	Interior dBA	Speed km/hr	Wayside dBA	Interior dBA
PHASE III (cont'd)						
Worn Stnd.	20	92	74.4	23	91.8	79.6
	20	89.5	77.2	20	--	75
New Stnd.	21	93.8	77.2	30	97.2	86
	20	89.8	75.5	23	91.2	77.5
	20	92.5	77	22	88.2	76.2
Acousta Flex/ Penn Bochum	20	77.5	71.5	26	77.2	72.2
	22	79	72.5	21	76	73.2
	20	81	74.6	23	76.5	70.2
	22	82.2	73.4	25	75.8	73.9
	19	78.8	74.5	20	74	70.6
	21	78.2	75.2	18	--	70.6
SAB	25	83.8	76.2	26	80.2	75.9
	21	82	73.8	18	78	71.2
	21	77.5	73.1	26	79	73.6

15TH STREET STATION TEST RESULTS

Train	Station Stop dBA	Station Skip-Stop speed-mph	Station Skip-Stop dBA
PHASE IB (unground rail)			
Worn Standard	80.1	28	82.8
	82.4	35	85.0
New Standard	80.3	39	83.3
	76.1	41	85.0
PHASE IIA (resilient wheels treated for first time)			
Acousta Flex	80.6	40	88.0
	83.0	42	88.3
Penn Bochum	80.8	43	86.5
	80.8	40	86.8
SAB	81.4	44	87.0
	83.7	40	87.3
PHASE IIB (ground rail)			
Worn Standard	82.6	40	90.5
	85.1	37	90.8
New Standard	81.8	38	84.5
	83.0	40	86.0
Acousta Flex	78.9	40	85.0
	80.3	44	87.0
Penn Bochum	78.6	39	86.5
	77.9	45	89.8
SAB	79.5	40	83.3
	82.0	40	84.0

ELEVATED STATION TEST RESULTS - PHASE IIB

Train	Station Stop dBA	Station Skip-Stop speed-mph	Station Skip-Stop dBA
Worn Standard	76.2	45	84.8
	78.4	42	84.0
New Standard	76.0	44	82.5
	75.3	41	82.3
Acousta Flex	77.9	39	79.8
	80.0	44	83.8
Penn Bochum	74.2	44	81.8
	81.3	--	----
SAB	77.6	38	80.0
	74.7	42	82.0

APPENDIX G

REPORT OF INVENTIONS

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REPORT OF INVENTIONS

A detailed review of work performed under this contract and the material contained in this report has not disclosed any discoveries or inventions. However, the work reported here represents improved engineering data on the costs and performance of three types of commercially available urban rail noise control techniques for which such data was previously inadequate. These techniques are resilient wheels, wheel truing, and rail grinding.

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